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Science and Education
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SEA-AR Staff Report

Appendix A

Biological Evaluation

Beltwide Boll Weevil/Cotton Insect Management Programs

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CATALOGING PREP

BIOLOGICAL EVALUATION
OF ALTERNATIVE BELTWIDE
BOLL WEEVIL/COTTON INSECT MANAGEMENT PROGRAMS

by

The Biological Evaluation Team

of the

USDA Interagency Working Group on the Boll Weevil

in cooperation with

Land-grant Universities

and

State Departments of Agriculture

FINAL REPORT

April 22, 1981

CONTENTS

FOREWORD

This is a report of the biological evaluation of alternative beltwide management programs for the boll weevil and other cotton insects. Supporting documents may be noted under separate binding as ATTACHMENTS. The evaluation involved many people and representatives of many cooperating agencies. For fear of slighting someone who may have contributed but had not come to the attention of the preparers of this report, only members of the Biological Evaluation Team, Boll Weevil Eradication and Optimum Pest Management Research Teams, and special consultants are listed. The preparers express appreciation to everyone who contributed to the development of the biological data or provided material for inclusion in the report.

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SUMMARY

Cotton is a major crop grown throughout the southern United States. Annual production is 10 to 14 million bales; value of the crop for the 1979-80 crop year was $5.1 billion. Insects are responsible for causing losses to cotton estimated in recent years at 7 to 19% of the crop. The boll weevil, a major insect pest of cotton that entered the United States from Mexico in 1892, is directly responsible for yield losses on about 7 million acres in the United States. It is also indirectly responsible for some of the losses now caused by the bollworm and the tobacco budworm. These indirect losses are associated with the destruction of natural enemies of bollworms and budworms by insecticides applied to control the boll weevil and with the increased cost of controlling strains of insects and mites that have developed resistance to insecticides.

Work at State, Federal, and private research laboratories during the 1960's and 1970's led to the development of a wide range of control components for suppressing populations of boll weevils and other insects that attack cotton. Meanwhile, systems for managing insect pests through the integration of control components were being developed. The culmination of many of these efforts was two cotton insect management trials, Optimum Pest Management (OPM) and Boll Weevil Eradication (BWE), that were initiated in 1978 and completed in 1980. The OPM Trial was conducted in Panola County, Mississippi; and the BWE Trial was conducted in North Carolina and Virginia. Results from these Trials, together with all other available information, should provide the basis for the design and evaluation of the most desirable cotton insect management program or programs for use in areas of the Cotton Belt that are infested with the boll weevil.

The OPM Trial was implemented by the Mississippi Cooperative Extension Service in Panola County, Mississippi, with grower, State, and Federal support.

The objective of this voluntary OPM Trial with incentives was to test the technical and operational feasibility of an area-wide cotton insect management program. The 3-year Trial was conducted on 32,000 to 40,000 acres of cotton. Incentives to encourage grower participation included government payments for applications of insecticides in late season to reduce populations of overwintering boll weevils. Growers that participated were required to see that their cotton was inspected, i.e., scouted weekly, and that a report was filed with Extension personnel. Additional educational services and technical assistance were provided by Extension pest management specialists who were employed to support the Trial and who resided within the Trial Area.

The procedures or program components used in each of the 3 years in the Trial included annual use of pheromone traps for monitoring populations of boll weevils; pheromone and light traps for monitoring populations of bollworms and budworms; application of insecticides in early season at the time pinhead size squares were present, if needed; scouting; inseason insecticide control of cotton insects by producers; four applications of insecticide in the fall to reduce numbers of overwintering boll weevils at no expense to growers; and voluntary destruction of stalks when harvest was completed before frost.

Grower participation in the Trial was at the rate of 98.7, 99.6, and 99.7% for 1978, 1979, and 1980, respectively. About 75% of the acreage was scouted by private consultants, 15% was scouted by producers, and 10% was scouted by a service provided by the Panola County Extension Pest Management Society.

The four late season applications of insecticide treatments used in 1978 and 1979 reduced numbers of boll weevils taken in traps during 1979 and 1980 by 78 and 94%, respectively, compared with trap catches in a Current Insect Control (CIC) area in Pontotoc County. These applications of insecticides seemed to have little, if any, adverse effect the following year on the populations of natural enemies of bollworms and budworms. In addition, there was no need for inseason applications of insecticide treatments for control of the boll weevil, and the number needed to control bollworms and budworms decreased significantly.

Finally, a review of yield records available for Panola County for a number of years indicated that OPM may have increased yields during the 3 years and a simulations model indicated that increases of 18 to 22 lb of lint per acre might be expected if OPM were implemented for the entire State.

Thus, the suppression of diapausing boll weevil populations with four insecticide treatments in the fall eliminated the need for inseason control of the boll weevils and reduced the number of treatments for control of bollworm and budworms. The OPM Trial, therefore, was considered a biological and technical success.

The BWE Trial was conducted by the Animal and Plant Health Inspection Service, USDA, with grower, State, and Federal support. It was a mandatory program authorized by a producer referendum. The objective was to determine whether eradication of an established population of boll weevil was technically and operationally feasible. The 3-year Trial was conducted on 16,000 to 34,000 acres of cotton in eastern North Carolina and Virginia. The Boll weevil was reported in this area in 1922, and it has infested cotton there since that time. The Trial Area was divided into two main areas, the

Evaluation Area and the Buffer Area. In addition, records were maintained separately for Chowan County which was in the Evaluation Area but isolated from all other cotton in the Evaluation Area by about 30 miles and from other infested cotton by about 120 miles. Extensive monitoring by pheromone traps and field inspections was conducted throughout the Trial Area. Similar monitoring was also done in an area outside of, but adjacent to, the BWE Trial Area.

During year 1 of the 3-year Trial, insecticides were applied in season to protect the crop and late season to reduce populations of overwintering weevils. In year 2, several suppression components, including limited use of diflubenzuron (Dimilin®), release of sterile weevils (139 per acre, i.e., a total of 11.2 million), and use of infield pheromone traps, were used. During year 3, the goal was the detection of any remaining weevils and the complete elimination of any that had survived (i.e., "native") or had been reintroduced from outside the Evaluation Area.

At the start of the BWE Trial, the population of weevils was relatively low because of the intensive use of insecticides for control of bollworms and budworms and two successive unusually cold winters in the years preceding the initiation of the Trial. On the basis of an estimated trap efficiency and assumed mortality due to fall applications of insecticides, 4 weevils/100 acres or a total of about 490 weevils were calculated to remain on 12,485 acres of cotton near the end of year 1. During the second year, after the fall applications of the first year, an estimated 15-25 overwintered weevils emerged in the Evaluation Area. This estimate was supported when intensive trapping resulted in the capture of only 7 overwintered "native" boll weevils. Two boll weevils were also trapped in fall traps in year 2; but since no boll

weevils were captured in traps (2 per acre) placed in cotton fields, reproduction of weevils within the Evaluation Area apparently did not occur.

During year 3 of the BWE Trial, a single headless boll weevil was found during the first trap inspection in May; this was believed to be carried over the winter in a stored trap. Also, 4 weevils were captured between August 18 and October 28 in migration traps just inside the Evaluation Area but distant from cotton fields. These weevils were considered to be migrants from outside the Evaluation Area on the basis of observed patterns of dispersal of boll weevils from infested cotton. Then, beginning September 11, one pupa and nine adult boll weevils were detected in a clump within a single field near the northern limits of the Evaluation Area. These weevils were believed to be the offspring of one reintroduced female. This infestation was eliminated by intensive trapping and cultural practices, and traps were placed there at a very high density and operated until November 15, a period of 7 weeks. No additional weevils were captured.

No boll weevils have been detected in the isolated county (Chowan County) within the Evaluation Area since June 1978, and no infestations of weevils were detected in the Evaluation Area between October 1978 and September 1980. In view of the expected rate of increase of a boll weevil population and the sensitivity of pheromone traps, statistical analysis indicated a probability of at least 0.9983 that the occurrence of a reproductive population would have been detected during this period. Review and analysis of relative data indicate that the boll weevils found in the Evaluation Area after June 1979 were "reintroduced" weevils. Therefore, "native" boll weevils were eradicated from the Evaluation Area.

Overall, in the North Carolina BWE Trial, the average number of insecticide applications decreased in the Evaluation Area and in the associated

Current Insect Control (CIC) area in North Carolina outside the Trial Area by 88% and 25%, respectively, during the Trial period compared to the 1974-1977 pre-trial averages. Populations of natural enemies of the bollworm and budworm (weekly average per acre) during July through August in the Evaluation Area were 6,289 and 17,070; and populations in the adjoining CIC area were 4,353 and 9,989 in 1978 and 1980, respectively.

Yield changes due to the BWE Trial were particularly difficult to estimate because of highly variable weather during the 3 years. However, there is no reason to believe that yield increases associated with the BWE Trial in North Carolina were any less than the 18-22 pound increases estimated for the OPM Trial in Mississippi.

Thus, following concurrent conservative use of insecticides and apparently increasing populations of natural enemies of bollworms and budworms, the eradication of a well-established boll weevil population was demonstrated to be a biological as well as a technical success.

The OPM and BWE Trials have been judged to be technical and biological successes, i.e., in the OPM Trial no inseason applications of insecticide were required for boll weevil control, and in the BWE Trial "native" boll weevils were eradicated from the Evaluation Area with a probability level of 0.9983. Moreover, certain of the procedures used in these Trials should be generally acceptable beltwide, at least in principle, for instance, (1) 99 to 100% participation by producers, i.e., total population management, (2) more intensive monitoring with traps and by field inspection, (3) elimination of the use of broad-spectrum insecticides for inseason control of boll weevil, (4) conservation of populations of natural enemies, and (5) reduction in amounts of insecticide used for control of bollworms and budworms. But there are some uncertainties associated with beltwide extrapolations, particularly in regard to the adequacy of proposed barrier zone(s) set up to prevent

reentry of boll weevils. Also, the various survey and suppression technologies would likely require some modifications in different areas of the Cotton Belt because of the existence of different environments and different cultural practices. However, the availability of a highly sensitive detection and monitoring system using pheromone traps, even at the lowest population level at which reproduction occurs, provides a means of employing available Boll Weevil suppression methods promptly and in a highly efficient manner. Thus, there is no reason to believe that the various technologies used in the Trials would be any less effective in other weevil infested areas of the Cotton Belt, with the possible exception of south Texas, than they were in the Trial areas, if these technologies are properly applied.

INTRODUCTION

The Problem

The United States ranks as one of the world's largest nations in terms of cotton production, export, and consumption. Nearly one-fourth, 14.9 million bales, of the world's cotton was produced in the United States in 1979. Value of the crop for the 1979-80 crop year was $5.1 billion.

Cotton is grown in 42 production sub-regions (Figure 1) as divided for the purposes of this evaluation. The boll weevil infests cotton acreage in 32 of these sub-regions (Figure 2)[1/]. The boll weevil (*Anthonomus grandis* Boheman) has caused extensive losses to cotton producers since its entry into the United States from Mexico about 1892 and its subsequent spread across the cotton belt. Estimates of annual losses to the cotton crop from the boll weevil in 13 boll weevil-infested states for the period 1909-1954, developed by the Bureau of Agricultural Economics, ranged from 1.3 to 31.2%, averaging 10.0% (Table 1) (Reference Attachment B. 13). Losses attributed to other insects averaged 3.1%. Losses to the cotton crop estimated by the U.S. Department of Agriculture for the period 1942-1951 averaged 10.1% to the boll weevil and ranged from 1.6 to 8.9% to other cotton insects for the states where the boll weevil occurs. In states where the boll weevil does not occur, estimated insect losses ranged from 2.9 to 10.1%. For the period

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[1/] A special case exists in Arizona in sub-region 40. When cotton is "stubbed" or regrown from the previous season's roots, between-season survival is permitted for boll weevils which migrate northward from Mexico late each year. These weevils then build up the second season to damaging levels.

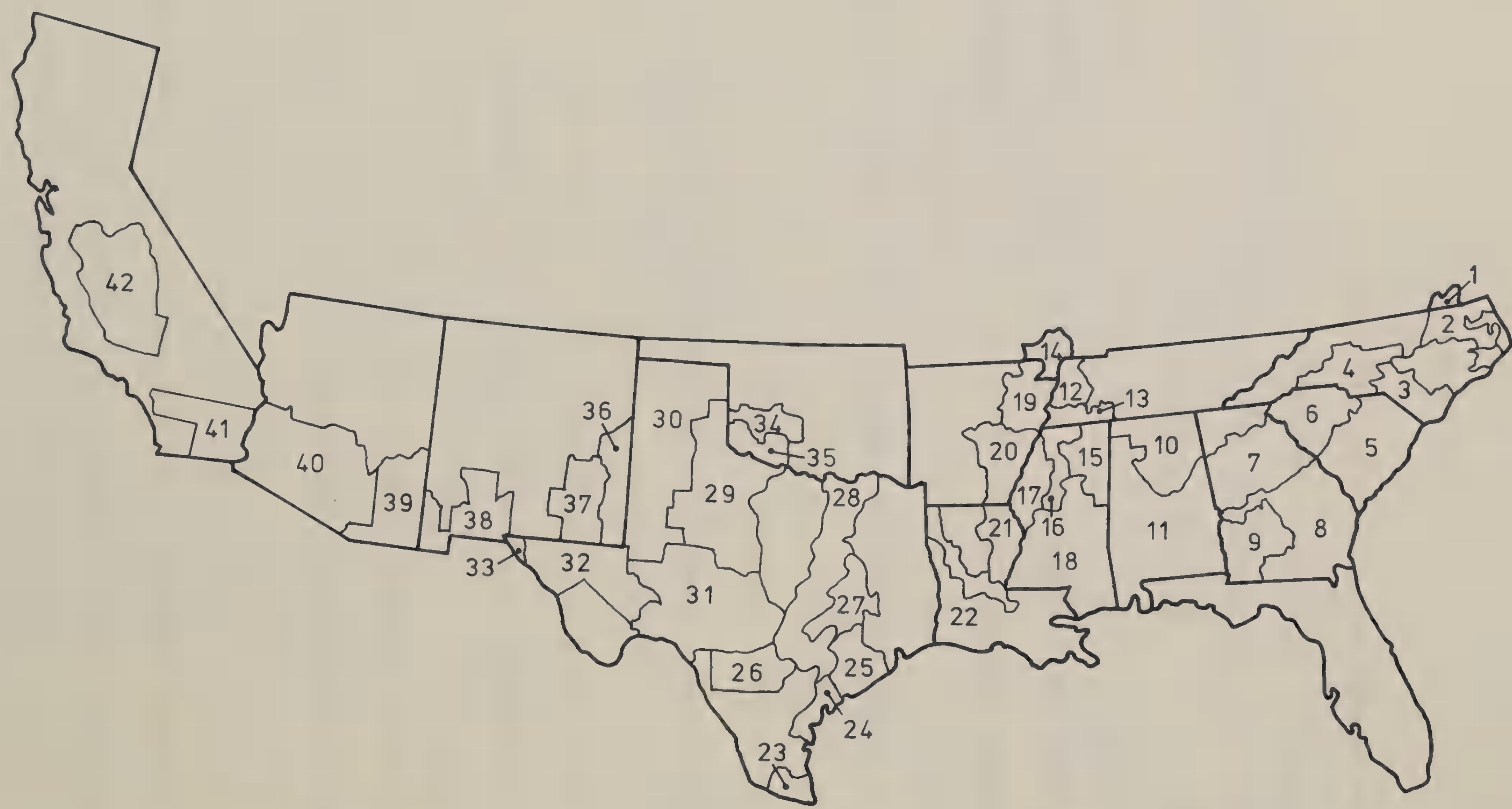


Figure 1. Production regions for boll weevil evaluation (regions 30, 32, 33, 36-39, 41, 42 are boll weevil free).

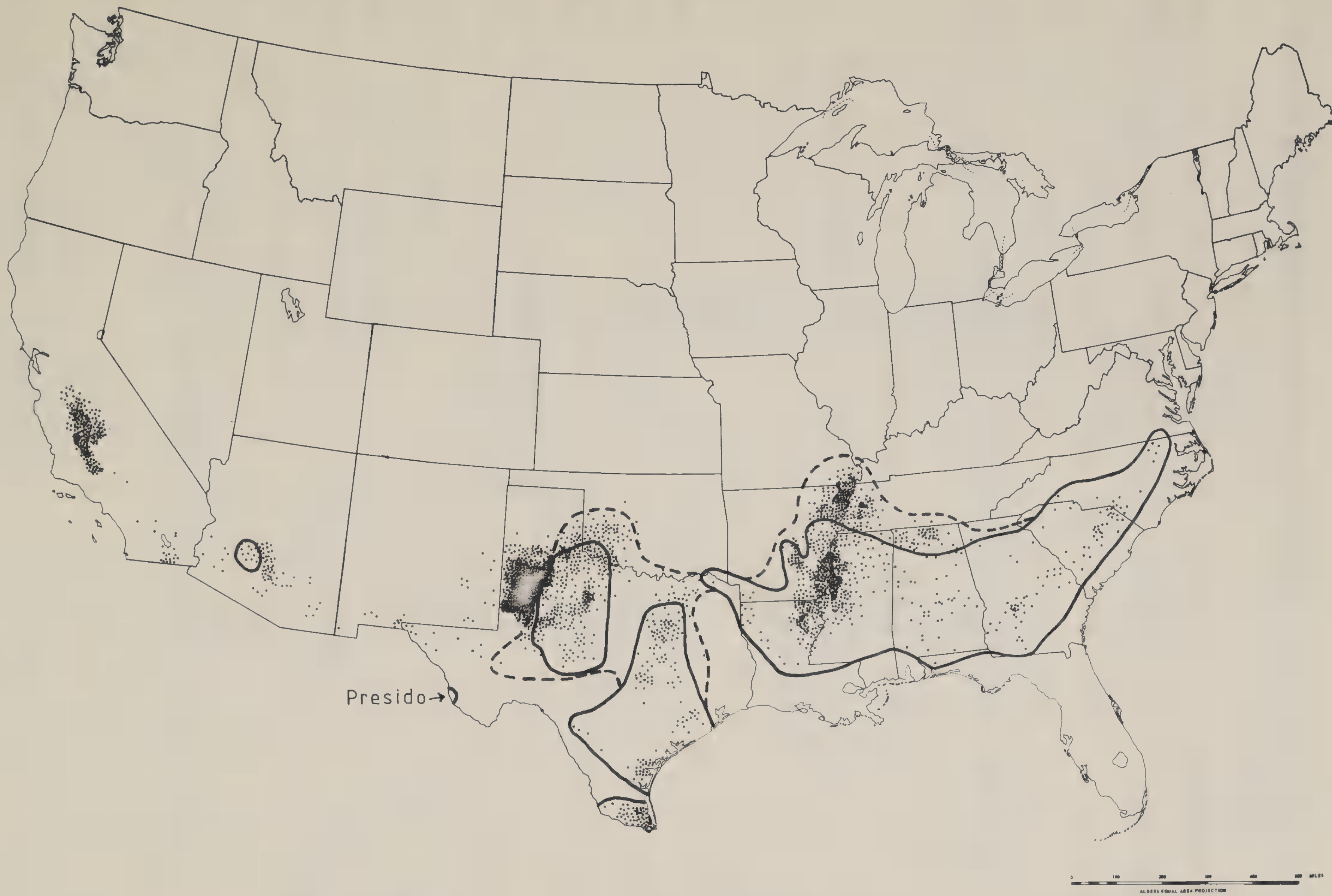


Figure 2. United States cotton, average 1974-78, with one dot per 5000 acres, and boll weevil distribution in solid lines with potential for reaching economic status in majority of years (Arizona in stubbed cotton only) and in dashed lines with potential for reaching economic status in occasional years.

Table 1. Average annual cotton yield losses to the boll weevil, 13 States, 1909-1954.

Year	Loss Percent	Year	Loss Percent
1909	6.1	1933	9.1
1910	5.1	1934	7.3
1911	1.3	1935	8.1
1912	3.5	1936	4.9
1913	7.5	1937	5.3
1914	6.1	1938	9.9
1915	10.2	1939	8.7
1916	14.2	1940	6.5
1917	8.6	1941	15.4
1918	5.4	1942	8.0
1919	13.0	1943	6.1
1920	19.7	1944	3.9
1921	31.2	1945	10.2
1922	23.3	1946	13.0
1923	19.2	1947	7.6
1924	8.1	1948	5.0
1925	4.1	1949	17.5
1926	7.1	1950	22.6
1927	19.4	1951	6.7
1928	14.1	1952	5.0
1929	13.3	1953	7.8
1930	5.0	1954	3.3
1931	8.3		-
1932	15.2	Average	10.0

1951-1960, average annual losses were estimated by the U.S. Department of Agriculture to be 19% with 8% attributed to the boll weevil. The National Cotton Council estimated an average yield loss of 7.4% to the boll weevil for the period 1970-1972. The Cotton Foundation estimated insect losses to the cotton crop for the period 1974-1976 to average 6.6% annually. Insect loss data were developed for the 1979 cotton crop under auspices of the Annual Conference on Cotton Insect Research and Control. Even with the sophisticated control measures currently used, the loss for the Cotton Belt was estimated to be 8.8% with 1.4% attributed to the boll weevil.

Dependable methods of control were not available until insecticidal chemicals came into use. Large quantities of insecticides are applied annually by growers for control of the boll weevil. The National Cotton Council estimated insecticide and application costs and yield losses at $260 million annually in 1970-1972 for boll weevil control (Table 2 and Attachment B. 14). Table 3 reports the average number of insecticide applications per treated acre by cotton production regions (Figure 3) for 1969-1977. For most regions the number of applications has been increasing. Table 4 presents the estimated insecticide material cost per harvested acre utilizing the same format as Table 3. The upward trend in number of treatments is generally reflected by a similar trend in insecticide costs. Table 5 lists pounds of selected materials for the period 1964-1977. Information summaries in Tables 3-5 trace the historical use of cotton insecticides (also Attachment B. 10) and may be indicative of the severity of infestations over time.

Insecticides applied for inseason (flowering period) boll weevil control cause an ecological disruption in the cotton ecosystems and have intensified certain secondary cotton pest problems, particularly the

bollworm, Heliothis zea (Boddie)/tobacco budworm, Heliothis virescens (Fabricius), complex. In addition, strains of the boll weevil resistant to the organochlorine insecticides have developed leaving the organophosphorous insecticides as the major class of insecticides available for control of the boll weevil. Resistance in the bollworm/budworm complex to both the organochlorine and organophosphorous insecticides has been reported from many areas of the Cotton Belt. (Pest Control: An Assessment of Present and Alternative Technologies; Volume III, Cotton Pest Control 1975. National Academy of Sciences, Washington, D.C.)

It should be noted that severe weather in the winters of 1976-1977 through 1978-1979 minimized the boll weevil problem. Population resurgence began in many areas in 1979 and increased in 1980, though population buildup was hampered by drought throughout most of the boll weevil infested states. Based on previous experience, the problem will intensify as weather patterns cycle and become favorable for population development (Table 1).

The yield losses accruing to the boll weevil, cost of control with insecticides, environmental considerations, ecological disruptions and intensification of secondary pest problems, and insecticide resistance--all of these have resulted in the consideration of alternate methods for managing the boll weevil and other cotton insects.

Table 2.--State summaries for annual yield losses plus control costs caused by the boll weevil.

State	Total ($ million)	Per Acre ($)	Yield Loss (%)
Alabama	45	81	18
Arkansas	14	12	3
Georgia	36	90	23
Louisiana	20	37	9
Mississippi	53	38	9
Missouri	3	9	3
North Carolina	12	69	18
Oklahoma	6	14	9
South Carolina	19	60	11
Tennessee	7	16	4
Texas	45	9	4
11 state total	260	25	7.4

* Averaged for the 1970-72 crops; yield losses were figured at $0.50 per pound for lint and $80 per ton for seed (Debord 1973).

Table 3.--Estimated number of applications per treated acre, selected years by cotton production region.[1/]

Cotton[2/] production regions	Number of applications 1969	1972	1974	1977	Normalized[3/]
SE-1	4.0	-	-	-	7.2
SE-2	7.0	13.0	14.0	18.9	12.7
SE-3	10.0	15.0	14.0	12.5	13.6
SE-4	4.0	5.0	8.0	5.5	5.5
SE-5	8.0	7.0	8.0	12.5	11.5
SE-6	6.0	-	-	12.5	7.9
SE-7	4.0	5.0	7.0	0.9	6.2
SC-1	4.0	7.0	7.0	8.5	8.9
SC-2	3.0	4.0	5.0	2.2	2.0
SC-3	2.0	2.0	4.0	3.7	2.2
SC-4	2.0	5.0	4.0	6.7	5.5
SC-5	6.0	9.0	10.0	-	5.3
SC-6	5.0	3.0	5.0	0.6	1.4
SC-7	1.0	2.0	2.0	0.3	1.0
W-1	2.0	2.0	2.0	1.8	-
W-2	7.0	9.0	7.0	9.4	-
W-3	4.0	9.0	7.0	-	-
W-4	2.0	-	-	1.1	-
W-5	7.0	3.0	-	1.1	-
W-6	3.0	-	-	-	2.3

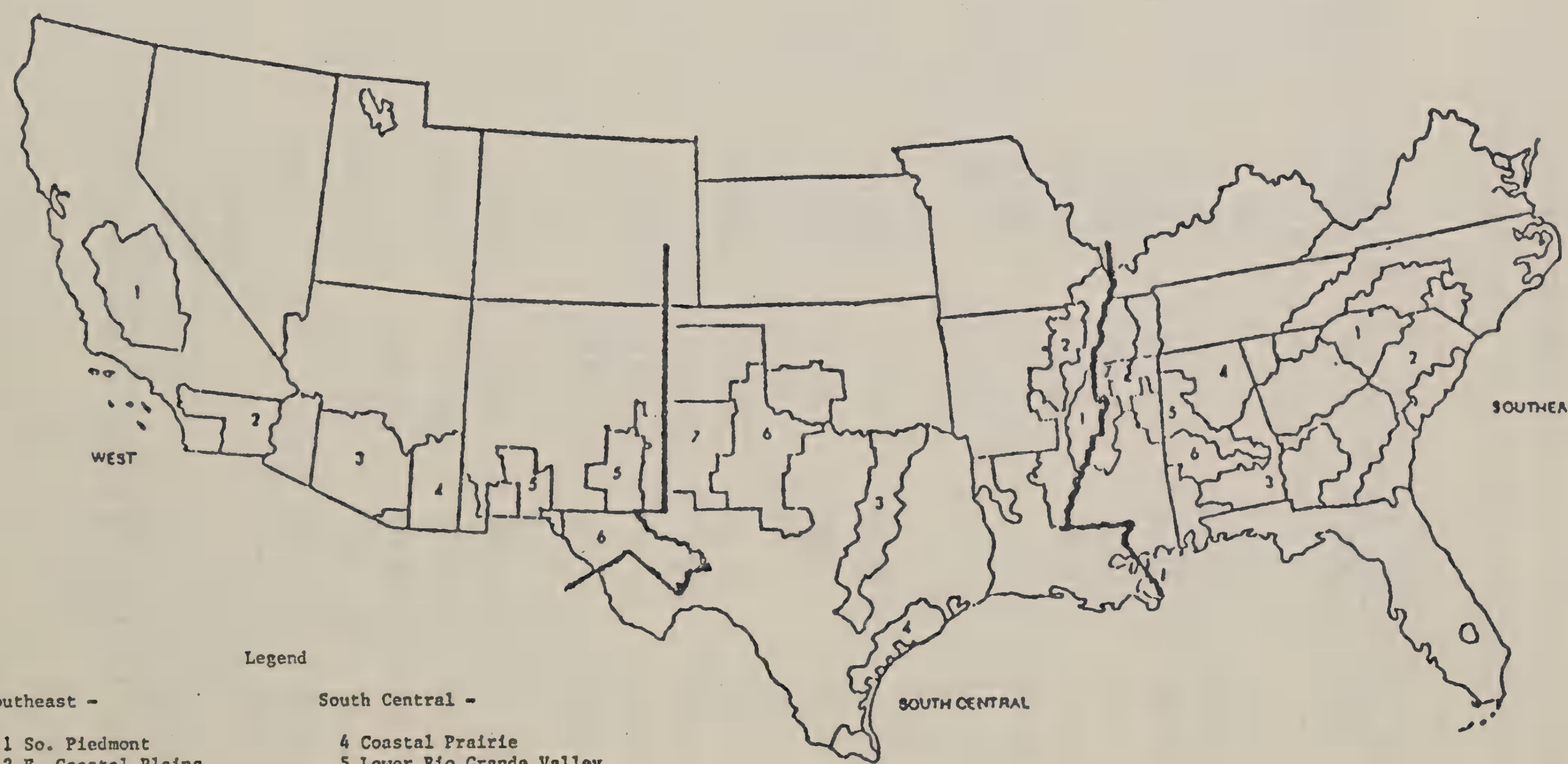
1/ See Attachment B. 2.
2/ See Figure 3 for location of production regions.
3/ Reflects average insect pressure and current technology.

Table 4.--Estimated materials cost per harvested acre, selected years, by cotton production region. (1979 Constant Dollars).[1/]

Cotton[2/] production regions	Materials cost per acre				
	1969	1972	1974	1977	Normalized
	- - - - - - - - 1979 Constant Dollars - - - - - - - -				
SE-1	16.54	-	-	-	43.68
SE-2	19.27	43.30	51.58	64.08	75.67
SE-3	31.89	57.49	67.77	39.86	81.05
SE-4	14.22	19.43	19.95	18.08	19.41
SE-5	20.19	16.69	22.84	39.86	61.71
SE-6	20.02	-	-	39.86	27.84
SE-7	11.02	12.73	13.94	2.69	27.05
SC-1	18.14	22.49	24.54	24.77	47.86
SC-2	9.17	9.36	16.95	6.06	6.35
SC-3	6.30	6.15	9.09	7.65	2.74
SC-4	6.42	21.96	19.98	21.05	19.41
SC-5	18.33	37.11	43.32	-	22.99
SC-6	18.45	11.49	13.14	2.26	4.12
SC-7	4.51	10.62	5.18	.87	7.58
W-1	11.07	20.06	12.21	7.05	-
W-2	33.46	77.95	41.11	33.70	-
W-3	24.96	63.05	37.74	-	-
W-4	12.20	-	-	2.55	-
W-5	27.99	17.50	-	2.55	-
W-6	17.16	-	-	-	11.27

1/ See Attachment B. 2.

2/ See Figure 3 for location of production regions.



Legend

Southeast -

1 So. Piedmont
2 E. Coastal Plains
3 So. Coastal Plains
4 Limestone Valley Sand Mtn.
5 Clay Hills
6 Black Belt
7 Brown Loam

South Central -

1 Mississippi Delta
2 N.E. Arkansas
3 Black Prairie

South Central -

4 Coastal Prairie
5 Lower Rio Grande Valley
6 Rolling Plains
7 High Plains

West -

1 San Joaquin Valley
2 So. California and S.W. Arizona
3 Central Arizona
4 High Southern Desert
5 Upper Rio Grande Pecos Valleys
6 Trans Pecos

FIGURE 3. PRODUCTION REGIONS FOR COTTON COST SURVEYS

Table 5.--Pounds of insecticide, selected materials, 1964-1977[1/]

Insecticide	Year								
	1964	1966	1969	1971	1972	1974	1976	1977	Normalized
					1,000 pounds				
Methyl parathion	8,760	7,279	17,280	22,988	34,392	54,011	19,981	15,528	13,368
EPN					1,692		6,140	5,213	7,106
Toxaphene	26,915	27,345	36,065	28,112	53,135	90,797	26,289	11,791	5,556
Methomyl								1,483	734
Monocrotophos			282			598		2.041	546
Dicrotophos		1,857	497	778	334		251	761	983
Endrin	1,865	510		1,068	2,810		311	679	
Permethrin								238	2,338
Parathion	1,636	2,181		2,560			680	909	6
Azinphosmethyl					1,800	595		383	922
Dimethoate								225	419
Fenvalerate								29	349
Chlordimeform								216	693
DDT	23,588	19,213	17,709	13,158	35,211				

1/ See Attachment B. 2.

Biological Evaluation

Two trials were conducted concurrently to compare boll weevil eradication and optimum pest management. Requirements were specified for extrapolating and evaluating the impacts of alternative programs beltwide. The biological aspects of this evaluation are presented here; environmental and economic aspects are presented in separate reports.

The Biological Evaluation objectives were:

1. To evaluate the degree of biological success of the Boll Weevil Eradication (BWE) Trial and the Optimum Pest Management (OPM) Trial.
2. To develop the relationships of the detrimental and beneficial cotton arthropods to the environment, cultural practices, need for insecticide applications and resulting yield.
3. To measure the impact under BWE and OPM compared with Current Insect Control (CIC) of the boll weevil, bollworm/tobacco budworms and predators and parasites on pesticide usage and cotton yield in North Carolina and Mississippi.
4. To provide inputs needed to assist in the estimation of beltwide biological impacts of alternative boll weevil/ cotton insect management programs by regions.

To meet the objectives listed above, the Biological Evaluation Team (BET) (see description of Research Teams on page vi) critically examined representative cotton fields from each of the trials (BWE and OPM) and from some nearby areas not included in the trials (CIC). Information gathered included topography, soil type, and fertility conditions, surrounding

habitat, weather data, crop history and plant growth characteristics, chemical applications, arthropod pest infestations, and counts of beneficials and other insects. In addition, data collected on infestations in all fields within the trials by APHIS personnel in North Carolina (BWE) and by Mississippi Cooperative Extension Service sponsored scouts in Panola ounty, Mississippi (OPM), were reviewed and analyzed by BET.

Close attention was given to interpreting boll weevil population counts, identifying sterile vs. wild weevils, interpreting long-range dispersal, and pinpointing sources of origin. The overall effects of the trials (immediate and long-range) on damage by other pests also was considered (Objective 1).

Arthropod populations within the cotton fields were considered as dynamic communities. Data obtained on populations from direct observations and special sample techniques were utilized to make recommendations on better pest and beneficial management schemes (Objective 2) (Attachment B. 12).

The impact under BWE, OPM, and CIC on populations of the boll weevil, bollworms, and selected beneficials and the resultant effect on cotton yield and pesticide use (Objective 3) were specifically addressed with the use of simulation models (Attachment B. 14 and 17).

The BET assisted the Delphi process, including organizing resource material, to aid in estimating the beltwide impact of alternative insect control options (Objective 4).

Two Research Teams (SEA and SAES cooperating), one in North Carolina and one in Mississippi, were organized to collect the specific data required primarily for biological evaluation. Several consultants assisted and a cooperative agreement with Mississippi State University, Department of Agricultural Economics, provided simulation modeling assistance.

Compatible programs were developed for storage and handling of operation

and evaluation data in the North Carolina State University computer for the BWE Trial and in the Mississippi State University computer for the OPM Trial.

In summary, the major components of the Biological Evaluation Plan included biological evaluation of the trials, biological impacts of the trials in comparison with CIC, and support in estimating beltwide biological impacts of alternative cotton insect management options.

COTTON INSECT MANAGEMENT

The Boll Weevil Problem in Perspective

The boll weevil, *Anthonomus grandis* (Boheman), was described in 1843 by C. H. Boheman from specimens received from Vera Cruz, Mexico. The first report of the occurrence of the boll weevil in the United States was received by the Department of Agriculture in the fall of 1894 from Brownsville, Texas. C. H. T. Townsend of the Division of Entomology was sent to Texas where he found several counties were infested with boll weevils and that serious damage had been caused by the pest since 1892.

Townsend's (1895) report relating to the area infested and the life history and habits of the boll weevil was published in March 1895 in Insect Life, Vol. 7, No. 4. He recommended that cotton stalks be destroyed to kill overwintering weevils and that a non-cotton zone be established to prevent further spread of the pest insect. The Department of Agriculture reported the seriousness of the pest to the Governor of Texas and urged immediate legislation to permit quarantines and remedial work. By 1895 the boll weevil had spread as far north as San Antonio and as far east as Wharton, Texas. The legislature of Texas appropriated funds for research and appointed a state entomologist to investigate means of control. The work on the boll

weevil by the Division of Entomology of the U.S. Department of Agriculture was discontinued at the end of the 1895 season.

The boll weevil continued to spread, with 1898 being an especially favorable year. By 1901 other states were threatened with invasion. Congress, therefore, appropriated special funds to support research designed to discover a means of preventing further spread. The resulting program was directed by W. D. Hunter. In 1908, Hunter demonstrated the cultural methods of controlling the boll weevil that had been developed and were recommended by the Division of the Farmers' Cooperative Demonstrations of the Bureau of Plant Industry. This organization developed into the present Extension Service of the U.S. Department of Agriculture.

In 1902, a laboratory was established at Victoria, Texas, to study the boll weevil. This work was moved to Dallas, Texas, in 1905 and from Dallas to Tallulah, Louisiana, in 1909; studies continued there until June 30, 1973.

The development of materials capable of controlling the boll weevil is of considerable interest (see Attachment B. 10 for a detailed discussion). Paris green was tested in 1896, but it was not an effective material. In 1908, lead arsenate was formulated as a dust and at first seemed a promising supplement to cultural methods of controlling the boll weevil. However, results were erratic, and the method was not recommended by the Bureau or used extensively by growers.

The first breakthrough came when the insecticide, calcium arsenate, was used in field tests against the boll weevil in 1916 (Coad 1918). Although problems with formulations were encountered, sufficient progress had been made by 1921 so that the material was tested in several sections of the Cotton Belt by Tallulah laboratory personnel. Machines for applying the material were developed at the same time.

The next step in boll weevil control was the application of calcium arsenate dust from airplanes. The use of airplanes was suggested by the success the Ohio Agricultural Experiment Station achieved with aerial applications of lead arsenate for control of the catalpa sphinx, Ceratomia catalpae (Boisduval), in 1921. However, the first such efforts against cotton insects were made against the cotton leafworm, Alabama argillacea (Hubner), in 1922. Thereafter, this method of application rapidly became widespread, and commercial companies soon maintained fleets of airplanes for use in controlling the boll weevil and the cotton leafworm.

Calcium arsenate dust and its application via aircraft was a major breakthrough in boll weevil control, but the insecticide was never widely accepted because its use often caused the development of infestations of the cotton aphid, Aphis gossypii Glover. This pest, if uncontrolled, would damage cotton sufficiently to offset any benefits obtained by controlling the boll weevil. Nicotine sulfate was developed as an aphicide, but it was difficult and unpleasant to formulate and apply, and it never gained wide acceptance.

The next major breakthrough was the development of organochlorine insecticides. However, the first of them, DDT, did not control the boll weevil. Only when BHC, toxaphene, aldrin, dieldrin, and heptachlor were developed did growers have more efficient insecticides than calcium arsenate (Ewing et al. 1947). When these materials were mixed with DDT, the mixture effectively controlled both the bollworm and the boll weevil; and parathion could be used as an aphicide when needed. Thus, once low-pressure, low-volume sprays were developed, growers and researchers felt that the situation was well in hand.

The widespread use of organic insecticides on cotton to protect the

crop from damage by the boll weevil resulted in the introduction of longer season cotton varieties, improved fertilization, and cultural practices to increase yields. In turn, insecticides were applied for a longer period to protect the crop.

The era of control with organochlorine insecticides was short-lived. By the mid-1950's, the boll weevil developed resistance to these insecticides (Roussel and Clower 1957; Walker and Hanna 1960). In the meantime, methyl parathion and later azinphosmethyl were developed for control of the boll weevil (Ivy et al. 1955; Robertson and Arant 1955). Ultra-low volume applications of malathion and azinphosmethyl came into the picture in the mid-1960's (Burgess 1965; Cleveland et al. 1966; Lloyd et al. 1972).

Resistance to the organochlorine insecticides in the boll weevil and increasing costs associated with its control caused the cotton industry to carefully consider alternative strategies for dealing with the problem. At the request of Congress, the boll weevil problem was reviewed in 1958. As a result of this review, the Boll Weevil Research Laboratory was established in 1961 on the campus of Mississippi State University, and research was strengthened at several USDA Cotton Insect Research Laboratories and state Agricultural Experiment Stations. The goal of this intensified research was to develop technology suitable for use in eliminating the boll weevil as an economic factor in cotton production.

The boll weevil was controlled by growers with insecticides developed by the chemical industry, which had been evaluated in USDA and state agricultural experiment station laboratories, and were recommended by the Federal and state Extension Services. Application of this chemical control technology varied widely from overuse to no use. Growers who did not apply insecticides for control of the boll weevil in their crops provided sanctuaries for the

boll weevil and a source of infestation for an entire community in the current and in the next crop season.

Entomologists have long recommended control of the boll weevil and associated pest problems in a manner consistent with modern concepts of insect pest management (Attachment B. 1). From the early work of Dwight Isley, an insect pest management system was developed in Arkansas in the 1930's and 1940's. Its major components were scouting, spot dusting, and early maturity of the cotton crop. In the late 1940's and early 1950's, K. P. Ewing and C. R. Parencia developed a system of early season insect control on a community-wide basis in Texas. In the mid and late 1970's, J. R. Phillips developed an insect population management system on a community-wide basis in Arkansas. In Texas, the development and use of short-season rapidly fruiting and determinate cotton genotypes (Attachment B. 4) (late 1960's-1970's), along with uniform planting (early and delayed), area-wide post-harvest stalk destruction, and field scouting have substantially reduced the boll weevil as an economic pest. Thus, over the years an escalation in cotton insect control practices occurred. Extension entomologists began to train scouts and encouraged scouting. Universities began to train pest management specialists. Cotton producers began to retain private consultants to assist in making pest management decisions. A pest management program funded by the U.S. Department of Agriculture was conducted from 1972 to 1974 to encourage cotton producers to use cultural (Attachment B. 3) and biological pest control measures in combination with insecticides, as needed, to protect their crops from damage. Since 1975, Federal funds have been provided to state extension services in cotton-producing states to develop cotton pest management programs. Much progress has been made in the improvement of insect population management especially in recent years. These

developments have resulted in the optimum pest management concept of insect control (Attachment B. 15).

The eradication and optimum pest management concepts differed significantly from the currently used insecticide technology in that all cotton acreage within an area selected for eradication, and a very high percentage of acreage in OPM, must be included for the procedures to be effective (Attachment B. 16). Procedures for eradication must include suppression of low as well as high density populations and a detection system with a high probability for quickly locating incipient infestations. A major change required by the eradication concept is the implementation of eradication technology on the entire acreage by a governmental agency, or a privately sponsored group, until eradication is achieved. In OPM, growers over a large area agree to use suppressive measures against the diapausing boll weevil population so that overwintered numbers are reduced to such low levels that treatment for control in the subsequent season may not be needed or is delayed until later in the season (Attachment B. 15).

Area-wide boll weevil suppression technology includes: (1) diapause control (Brazzel et al. 1961) and reproduction-diapause control (Lloyd et al. 1966) procedures to suppress boll weevil populations in the fall; (2) a detection system based on pheromone-baited traps (Cross and Mitchell 1966; Tumlinson et al. 1969; Leggett and Cross 1971); and autocidal procedures based on mass-reared and released sterile boll weevils (Gast and Vardell 1966; Davich et al. 1965; Klassen and Earle 1970). In 1971-1973, a large-scale field test incorporating this newly developed technology was implemented in southern Mississippi with adjacent areas in Louisiana and Alabama. The test area was selected to represent the most difficult boll weevil problem existing in the Cotton Belt. The Pilot Boll Weevil Eradication Experiment included

the following supression components:

1971

1. Inseason control by growers.
2. Reproduction-diapause control with insecticide treatments applied by the operations agency (APHIS, USDA).
3. Defoliation and stalk destruction.

1972

1. Pheromone-baited traps placed around cotton fields during the spring.
2. Pheromone-baited trap crops.
3. Inseason control with insecticides applied by the operations agency.
4. Reproduction-diapause control with insecticides applied by the operations agency.

1973

1. Pheromone-baited traps placed around cotton fields during the spring.
2. Pheromone-baited trap crops during the spring.
3. Release of sterile male boll weevils.

The major results of the experiment follow:

1. A high degree of suppression could not be attained with chemical and cultural measures applied during the fall unless the boll weevil population was held to a reasonably low level during the growing season.
2. A thorough inseason insecticide program carried out on all of the cotton acreage within a prescribed area followed by a thoroughly applied reproduction-diapause spray schedule in the fall reduced overwintering

boll weevil populations to a very low level.

3. Pheromone-baited traps provided information on boll weevil distribution and abundance and added an important suppression component against low populations.

4. The release of treated boll weevils, even though less than 100% sterile, effectively suppressed the native low density populations.

5. Enough movement of boll weevils from heavily infested cotton through the intensively treated Buffer Area of 12-20 miles caused detectable infestations for at least 25 miles from heavily infested cotton into the northern end of the core area.

6. Despite generally inadequate financing, inexperienced operational personnel, relatively poor quality sterile boll weevils, and the use of sterility and attractant techniques not yet fully perfected, the boll weevil population by Year 3 was reduced to a remarkably low level throughout the core area.

7. In cotton fields isolated by more than 25 miles from heavily boll weevil infested cotton, no reproduction was detected by available survey methods in a total of 170 cotton fields during 2 generations of development. Thirty four of sixty-six cotton fields isolated by less than 25 miles had low level incipient infestations. The incipient infestations were reduced to non-detectable levels by thorough insecticide applications applied for one generation.

Reports on the evaluation of the Pilot Boll Weevil Eradication Experiment were prepared by the Technical Guidance Committee for the Pilot Experiment (Knipling 1976) and by the Review Committee of the Entomological Society of America (Eden 1976). The Technical Guidance Committee identified the following specific research needs:

1. Improved mass-rearing procedures to assure the capability of producing adequate numbers of high-quality boll weevils for sterilization and release.
2. Improved sterilization techniques to assure the attainment of maximum and consistently high levels of sterilization with a minimum detrimental effect on the vigor and mating competitiveness of the males.
3. New methods of sterilizing both sexes of the boll weevil so as to obviate the cost of separating sexes and to reduce costs and logistic problems associated with feeding boll weevils for six days before release.
4. Continued investigations on grandlure (boll weevil pheromone) to develop the most effective and least costly method of employing the attractant for: (a) suppression, (b) as a means of detection and population assessment, and (c) as a means of monitoring progress in population suppression.

The Review Committee of the Entomological Society of America identified the same research needs.

The Technical Guidance Committee for the Pilot Experiment concluded that it was technically and operationally feasible to eliminate the boll weevil as an economic pest in the United States by the use of techniques that were ecologically acceptable. The Review Committee of the Entomological Society of America did not agree on whether technical feasibility of eradication of boll weevil populations was demonstrated. It concluded that an attempt to eradicate the boll weevil should be a socio-political decision. It recommended that all members of the Entomological Society of America inform themselves as to the long-range environmental and economic benefits that would result from a successful eradication program and weigh the benefits against the costs involved.

Considerable controversy developed over the results obtained in the

experiment. Availability of technology to achieve eradication was questioned. An agreement was reached (assuming funds be made available) whereby a Boll Weevil Eradication Trial would be conducted in northeast North Carolina and adjacent areas of Virginia concurrently with an Optimum Pest Management Trial in Panola County, Mississippi, to determine whether boll weevil eradication was feasible and to compare the alternatives, biologically, economically and environmentally (Attachments B. 18, 19, and 20). The Trials began in 1978 and were completed at the end of 1980.

Technical aspects and operational plans for the Optimum Pest Management and Boll Weevil Eradication Trials are presented in other sections of this report. These trials were large-scale tests of area-wide suppression technology for population management or eradication. The new area-wide suppression systems were compared with current insect control management systems which rely on inseason insecticide treatments for reducing populations below action levels (economic thresholds).

Overview of Technology Available[1/]

Technology Available for Current Insect Control Programs

Technology used in current insect control programs varies from region to region. Components included in many control programs include: (1) early

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1/ In wide areas of Texas cotton land, and to some extent in other boll weevil infested states, special consideration is given to short season varieties and to cultural practices such as early planting date, reduced fertilizer use and irrigation, and post harvest destruction. Also, with supported alternative programs consideration would be given to managing the bollworm/ tobacco budworm with microbial insecticides as a first choice.

season control of the boll weevil and other insects with insecticides; (2) scouting to determine the presence of damaging insect population levels and to determine effectiveness of insecticidal control procedures; (3) in-season control of boll weevil, other damaging insects, and spider mites; and (4) voluntary diapause control for the boll weevil. (Reference Attachment B. 10 for a detailed summary of insecticides and dosages currently used for the control of cotton insects.) Funding for the Cooperative Extension Services will be at current levels. (Table 6):

Technology Available for Optimum Pest Management of the Boll Weevil and Other Cotton Insects

Optimum Pest Management of the boll weevil and other cotton pests as demonstrated in the OPM Trial differs from current insect control programs because boll weevil populations are suppressed during the fall by diapause or reproduction-diapause control programs. By reducing boll weevil populations during the fall, the need for insecticide treatments for boll weevil control is delayed the next crop season, thus preserving beneficial arthropods which attack the bollworm/tobacco budworm complex. Components of an Optimum Pest Management program include: (1) diapause or reproduction-diapause control treatments during the fall (see exception below); (2) scouting to determine the presence of damaging insect population levels; (3) and in-season control of the boll weevil, other damaging insects, and spider mites. These procedures are repeated each year as indicated in Table 6. Definitions of some OPM options are described below (Table 6):

1. Optimum Pest Management with Incentives (OPM-I) utilizes Federally funded diapause control treatments during the fall and pinhead square treatments as needed in order to suppress the boll weevil population so that 90% or more of the acreage will not require

Table 6. Application of Technology in Indicated Boll Weevil Control, Suppression, or Eradication Strategy

Current Insect Control Program (CIC)[a/]	Modified Optimum Pest Management (MOPM)[b/]	Optimum Pest Management Programs (OPM-I, OPM-PI, and OPM-NI)[c/]	Boll Weevil Eradication Program (OPM-BWE and CIC-BWE)[d/]
Year I			
1. Short season variety[e/] 2. Cultural practices[e/] a. Optimum planting date b. Reduced fertilizer and irrigation (when appropriate) c. Post harvest stalk destruction 3. Scouting 4. Boll weevil control a. Early season b. In-season 5. Managing other cotton insects by selective use of insecticide	1. Short season variety[e/] 2. Cultural practices[e/] a. Early planting date b. Reduced fertilizer and irrigation (when appropriate) c. Post harvest stalk destruction 3. Scouting 4. Boll weevil control a. Early season b. In-season 5. Managing other cotton insects by selective use of incesticides 6. Manage bollworm/tobacco budworm with microbial insecticides as a first choice and other effective insecticides as necessary[e/]	1. Short season variety[e/] 2. Cultural practices[e/] a. Early planting date b. Reduced fertilizer and irrigation (when appropriate) c. Post harvest stalk destruction 3. Scouting 4. Boll weevil control a. Early season b. In-season 5. Managing other cotton insects by selective use of insecticides 6. Manage bollworm/tobacco budworm with microbial insecticides as a first choice and other effective insecticides as necessary [e/] 7. Diapause or reproduction-diapause control in late summer and fall for area-wide population suppression	1. Short season variety[e/] 2. Cultural practices[e/] a. Early planting date b. Reduced fertilizer and irrigation (when appropriate) c. Post harvest stalk destruction 3. Scouting 4. Boll weevil control a. Early season b. In-season 5. Managing other cotton insects by selective use of insecticides 6. Manage bollworm/tobacco budworm with microbial insecticides as a first choice and other effective insecticides as necessary[e/] 7. Diapause or reproduction-diapause control in late summer and fall for area-wide population suppression[f/] 8. Grandlure-baited peripheral traps in the fall[f/]
Year II			
(Same as Year I)	(Same as Year I)	(Same as Year I)	1. Short season variety[e/] 2. Cultural practices[e/] a. Early planting date b. Reduced fertilizer and irrigation (when appropriate) c. Post harvest stalk destruction 3. Scouting 4. Grandlure-baited peripheral traps in the spring around Year I fields[f/] 5. Release of sterile boll weevils at pinhead square stage of plant, growth and continue for 3 to 5 weeks.[f/] 6. Foliar sprays of diflubenzuron at pinhead stage of plant growth and continued for 3 to 5 weeks. Close diflubenzuron treatments with boll weevil insecticide to kill emerged overwintered boll weevils.[f/] 7. Infield grandlure-baited traps for detection of incipient boll weevil infestations. Incipient infestations eliminated with most appropriate suppression method.[f/] 8. Managing other cotton insects with natural occurring beneficial insects, or with insecticides.
Year III and subsequent years			
(Same as Year I)	(Same as Year I)	(Same as Year II)	1. Scouting 2. Managing other cotton insects with natural occurring benefical insects, other suppression methods which preserve beneficial insects or with insecticide. 3. Grandlure-baited traps for monitoring any incipient boll weevil populations[f/]

[a/] CIC implies current funding for the Cooperative Extension Services.

[b/] MOPM implies increased funding for the Cooperative Extension Services.

[c/] OPM-I, PI, and NI implies increased funding for the Cooperative Extension Services.

[d/] CIC-BWE implies current funding for the Cooperative Extension Services in an eradication program, while OPM-BWE implies increased funding for the Cooperative Extension Services one year prior to an eradication program, during and following the program.

[e/] Applies primarily to Texas

[f/] Conducted by BWE Operations

mid-season treatments before the onset of Heliothis pressure. While implementation of technology for OPM-I will vary among different parts of the Cotton Belt, adequate incentives will encourage a high level of participation. Increased technical assistance by the Cooperative Extension Services will be included as a part of OPM-I.

2. Optimum Pest Management with the incentives (OPM-PI) utilizes the same technology as OPM-I except incentives are phased out by Year 4. Increased technical assistance and supervision by the Cooperative Extension Service will be included as a part of OPM-PI.
3. Optimum Pest Management with no incentives (OPM-NI) recommends the same technology as OPM-I and OPM-PI, except that the incentives are not provided. Assistance and supervision by the Cooperative Extension Services will be included as a part of OPM-NI.
4. Modified Optimum Pest Management (MOPM) will not necessarily include diapause control or early season insecticide treatment programs for boll weevil suppression. (However, all available technology can be used in a MOPM program.) MOPM will provide increased technical assistance and guidance by the Cooperative Extension Services.

Technology Available for Use in a Boll Weevil Eradication Program (CIC-BWE and OPM-BWE)

Technology employed in proposed future boll weevil eradication programs would vary from region to region depending upon the size of the infesting boll weevil populations. Technology available for use in eradication programs include the following--Year I: (1) inseason control of the boll weevil and other pests, and (2) diapause or reproduction-diapause of the boll weevil in

the fall; Year II: (1) grandlure (pheromone)-baited peripheral traps for survey and suppression (Attachment B. 8), (2) release of sterile boll weevils (attachments B. 7 and 11), (3) foliar sprays of diflubenzuron for boll weevil suppression where warranted (Attachment B. 9) and (4) grandlure-baited infield traps for detection of incipient boll weevil infestations; Year III: (1) grandlure-baited peripheral traps for survey and detection, and (2) grandlure-baited infield traps for detection of incipient boll weevil infestations. CIC-BWE implies funding for the Cooperative Extension Services at the current level of funding, while their funds would be increased with OPM-BWE.

A comparison of application of technology in current insect programs, Optimum Pest Management and Boll Weevil Eradication, is presented in Table 6.

Other Technology Available for Control of the Boll Weevil and for Managing Other Cotton Insects

In addition to technology previously identified, varieties with resistance to the boll weevil and other cotton insects are being developed (Attachment B. 4). Some have been introduced as commercial cultivars. Other varieties, commonly referred to as "short season cottons," begin fruiting earlier and mature earlier than "full season" varieties. The earlier maturity (or short season cottons) eliminates the development of late season insect populations in areas where they have been adapted for grower use. The use of resistant varieties or types of cotton modified for early harvest will enhance the effectiveness of other suppression systems. This management strategy, along with selective early-season insecticide use and post-harvest stalk destruction in central and south Texas, is effective in controlling the boll weevil. Area-wide, uniform, delayed planting in the

rolling plains of Texas has been highly effective in minimizing damage by taking advantage of suicidal emergence of the boll weevil in the spring. In addition, beneficial arthropod populations are preserved and allowed to suppress other pests, particularly the bollworm/tobacco budworm (Attachment B. 5). Based on field scouting (Attachment B. 12), insectcides may be applied at specific action levels. The optimum approach is the use of a microbial insecticide (Attachment B. 6) as a first choice for bollworm/ tobacco budworm suppression. This action precludes engaging in a costly season-long insecticide control program. Conventional insecticides are used as a last alternative in this management scheme.

Restrictions to Technology Available

Recent developments in technology available for cotton insect control have been restricted by actions of regulatory agencies. These actions have restricted development of chemical insecticides to those of short residual activity, non-persistence in soil and plants, and greater biological selectivity; all of which have increased cost of insecticides. However, such regulatory restrictions are serving a useful purpose in that they encourage development of a more holistic insect management system. Although the overall impacts of regulatory actions may result in short-term increased costs to the producer, improved methods of managing cotton insects should provide greater long-term benefits.

BOLL WEEVIL TRIALS

Boll Weevil Eradication Trial

The Boll Weevil Eradication (BWE) Trial was conducted by APHIS in the northeastern part of North Carolina with a small adjoining area in Virginia,

1978-1980 (see Attachment C). The Trial and adjoining Current Insect Control (CIC)-practice areas are identified as follows:

1. The Evaluation Area for the BWE Trial includes the principal cotton-producing counties of Northampton, Halifax, Hertford, Bertie, Edgecombe and northern Nash counties in North Carolina. Small cotton plantings were also present in Greenville and Southampton counties in Virginia.

2. Chowan County, North Carolina, is also a part of the Evaluation Area but was used as a Methods Development Area by the APHIS operational group implementing the BWE trial.

3. The Buffer Area for the BWE Trial includes the principal cotton-producing counties of Sampson, Harnett, Johnston, Cumberland, Wilson, and southern Nash in North Carolina.

4. Scotland and Robeson counties are located on the southern coastal plain of North Carolina and represent one of two CIC-practice areas.

5. Cleveland County, North Carolina, the second of two CIC-practice areas, is located in the western foothills (Piedmont) of North Carolina.

Technology

Year I (1978):

1. Use of pheromone-baited traps during the spring and summer around 1977 cotton fields for survey and detection.
2. Inseason control of boll weevil and bollworms.
3. Diapause control with insecticides during the fall to reduce overwintering boll weevil populations.

Year II (1979):

1. Pheromone-baited traps during the spring and summer (1 trap per acre) around 1978 cotton fields for survey and detection.

2. Release of sterile boll weevils (for 4 weeks) beginning at initiation of squaring for suppression of surviving emerged overwintered boll weevil populations.
3. Four foliar sprays of diflubenzuron (0.0625 lb. per acre per application) on ca. 400 selected acres in Evaluation Area and ca. 900 acres in the Buffer Area. (Diflubenzuron treatments were concurrent with the release of sterile boll weevils. One application of azinphosmethyl [0.25 lb. per acre] was applied to the 400 acres treated with diflubenzuron in the Evaluation Area following the fourth treatment.)
4. Pheromone-baited infield traps (2 per acre) from mid-July until late August.
5. Inseason control of bollworms by growers.
6. Pheromone-baited traps around 1979 cotton fields at rate of 1 per acre from late August until frost.

Year III (1980):

1. Pheromone-baited traps around 1979 cotton fields during spring and summer.
2. Pheromone-baited infield traps (ca. 1 per acre) from mid-July until late August.
3. Suppression measures utilized as appropriate.

Evaluation Criteria

The evaluation of BWE was based on: (1) an expected 10 percent or less of the trial acreage being infested by boll weevil during the second year with population levels on that acreage reduced to 3 or less weevils per acre; (2) zero native boll weevil infestations in the Trial Area after July 15 of the third year of the program operations as determined by trapping survey

and other available methods; (3) acceptable levels of bollworm and beneficial arthropod populations, and (4) acceptable levels of pesticide usage and yield.

Evaluation Methodology

The Boll Weevil Eradication Trial (BWET) began in 1978 and continued through the 1980 crop season. In 1977, baseline data for the Biological Evaluation of BWET in North Carolina were collected in Cleveland County (8 fields), Anson County (8 fields), Scotland and Robeson counties (8 fields), Chowan County (6 fields), and Northampton, Halifax, and Edgecombe counties (18 fields). Because of dry weather and heavy bollworm infestations in 1977, acreage of cotton in Anson County was severely reduced in 1978. Therefore, collection of field data was discontinued in Anson County after the 1977 crop season. Locations of monitored areas are shown in Figure 3A.

In 1978, the number of fields monitored was increased to 219 fields. A total of twenty-four of these fields were monitored intensively (semi-weekly).

1. In the Evaluation Area of the Eradication Trial (excluding Chowan County), 126 fields were monitored including 8 intensively monitored fields. Fields were located (through 1980) in Northampton, Halifax, Hertford, Bertie, Edgecombe, and northern Nash counties.

2. In the Buffer Area (Dunn area) of the BWET, 35 fields were monitored including 4 intensively monitored fields. Fields were located in Sampson, Harnett, Johnston, Cumberland, Wilson, and southern Nash counties.

3. In Chowan County, 19 fields were monitored including 4 intensively monitored fields. Chowan County is an isolated cotton growing county on the eastern edge of the Evaluation Area and was used through 1980 as a

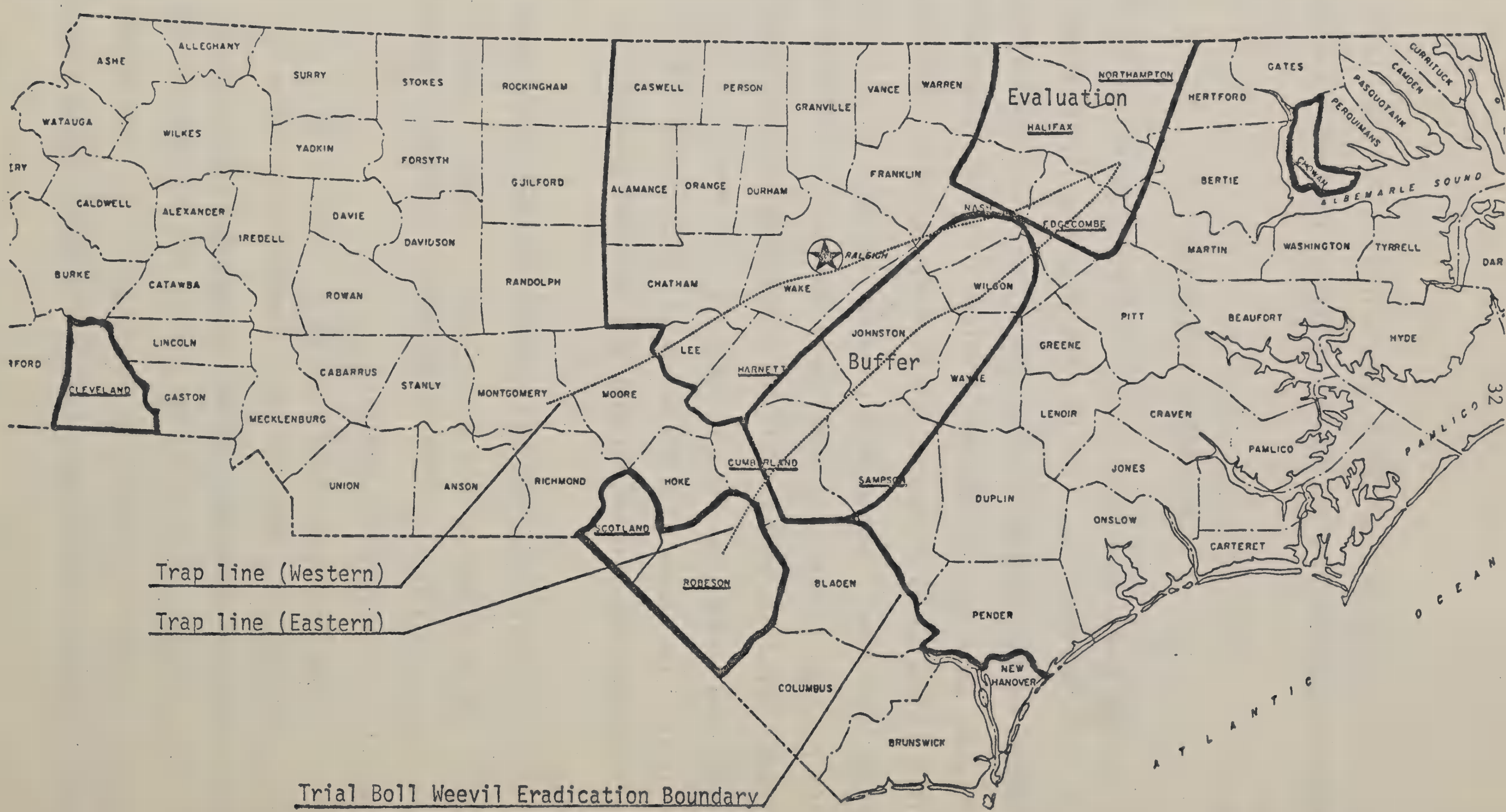


Figure 3A. Location of sampling areas and trap lines for Biological Evaluation of the Boll Weevil Eradication Trial in North Carolina, 1978, 1979, and 1980.

Methods Development Area by the APHIS operational group implementing the BWET.

4. In Scotland and Robeson counties, 19 fields were monitored including 4 intensively monitored fields. Scotland and Robeson counties are located outside the Eradication Trial Area in the southern Coastal Plain area of North Carolina and represented one of two CIC-practice areas.

5. Cleveland County, the second of two CIC-practice areas, is located in the western Piedmont or foothills of North Carolina. In Cleveland County, 20 fields were monitored including 4 intensively monitored fields.

In 1979, there were 206 fields monitored in the Boll Weevil Eradication Trial. Of these, 26 were monitored intensively (semi-weekly).

1. In the Evaluation Area of the Eradication Trial, 115 fields were monitored including 10 intensively monitored fields.

2. In the Buffer Area (Dunn area) of the BWET, 21 fields were monitored including 4 intensively monitored fields.

3. In Chowan County, 28 fields were monitored including 4 intensively monitored fields.

4. In Scotland and Robeson counties, 21 fields were monitored including 4 intensively monitored fields.

5. In Cleveland County, 21 fields were monitored including 4 intensively monitored fields.

In 1980, there were 155 fields monitored in the Boll Weevil Eradication Trial. Of these, 24 were monitored intensively (semi-weekly).

1. In the Evaluation Area of the Eradication Trial, 68 fields were monitored including 8 intensively monitored fields.

2. In the Buffer Area (Dunn area) of the BWET, 21 fields were monitored including 4 intensively monitored fields.

3. In Chowan County, 25 fields were monitored including 4 intensively monitored fields.

4. In Scotland and Robeson counties, 20 fields were monitored including 4 intensively monitored fields.

5. In Cleveland County, 21 fields were monitored including 4 intensively monitored fields.

Dynamic crop information such as weather, fruiting, missing fruiting forms plant height, rooting depth and number of main stem nodes were recorded. Beneficial and pest arthropod populations were monitored with weekly estimates of populations[1/] damage in the fields. The size of beneficial arthropod populations was estimated by sampling with a D-Vac insect collecting machine. The sample was returned to the laboratory where the numbers of each species (or a group of species) were determined.

Static crop information such as planting date, cultivar, row spacing, soil types, surrounding vegetation, insecticide applications, and yields were recorded.

Results of Research Team Studies

1. Comparison of insect populations and damage for 1977 fields and 1978, 1979, and 1980 intensively sampled fields

Boll Weevil Damage: The estimated number of boll weevil punctures (feeding and oviposition) in the 5 sampled areas for 1977-1980 is shown in Figures 4-8 (see figures beginning page 46). Boll weevil infestations were light in 1977. The Evaluation Area (Figure 4) experienced peak damage the first week in July in 1977 (ca. 300 punctures per acre). The boll weevil infestation was also

[1/] All populations cited in this report could be adjusted to actual values per acre according to Smith et al. (Attachment B. 12).

very light in 1978 when a few punctures were detected the week of July 15 and again in late August. In 1979, feeding punctures were detected in July and early August. These feeding punctures were attributed to sterile weevils released from June 18 through July 9. In 1980, no feeding or oviposition punctures were detected in the intensively sampled fields.

The Buffer Area (Figure 5) experienced peak boll weevil damage during early August in 1978 (ca. 900 punctures per acre). In 1979, peak damage in the Buffer Area occurred in mid-July. These were feeding punctures (except for 1 egg puncture containing a sterile egg) and were attributed to the release of sterile boll weevils. During the fall of 1979, the Buffer Area was lightly infested with boll weevils and received 4 applications of azinphosmethyl during September and October for the control of diapausing boll weevils. No feeding punctures were detected in 1980 in the intensively sampled fields. However, trapping results indicated that low levels of weevil reproduction may have resulted from weevils migrating up from Scotland and Robeson counties. Therefore, 4 applications of azinphosmethyl (diagram control) were made during September and October of 1980.

In Chowan County (Figure 6) during 1977, peak boll weevil damage occurred on July 7 when ca. 1,000 punctures per acre were observed. During 1978, 5 treatments of diflubenzuron (0.0625 lb. per acre) were applied at weekly intervals beginning when cotton reached the 8-leaf stage. The diflubenzuron treatments were closed with one application of azinphosmethyl (0.25 lb. per acre). Approximately one pheromone trap per acre was installed around 1977 field locations beginning in late April. In addition, one infield trap per acre was installed in mid-July and maintained until early September when they were removed to perimeter locations. Ten overwintered weevils were captured during the spring of 1978 around 1977 cotton fields. The final weevil was captured on June 28, 1978. No weevils were detected by infield

traps in 1978. Similar trapping procedures were employed during 1978 and 1980. The last weevil captured in Chowan County was the June 28, 1978 record.

Scotland-Robeson counties (Figure 7) experienced relatively low but sustained boll weevil damage during the unfavorable crop year of 1977. Organophosphate insecticides were used extensively during 1977 in an attempt to control the extremely heavy bollworm infestation. As a result of the intensive insecticide treatments in 1977 and the severe winter of 1977-1978, boll weevil populations were very light during 1978. However, in 1979 and 1980, economically important boll weevil infestations were present and required insecticide treatments during late July and August. Because of the intensity of the boll weevil infestation in late August and September, insecticide treatments for the control of diapausing weevils were recommended to growers. However, this voluntary diapause control program was implemented by only a few growers in this area.

In Cleveland County (Figure 8) during 1977, boll weevil infestations were observed in some fields. Most fields in the western part of the county had sizeable populations during the fall. However, the severe winter of 1977-78 appeared to greatly reduce the number emerging in 1978. The first infested squares were observed during the week of July 21 with a peak infestation of ca. 1,800 squares per acre appearing in mid-August. Due in part to over-wintering mortality, no boll weevils were detected until the 2nd week of August in 1979. At this time, some fields contained up to 30% punctured squares. During August, most of the sampled fields developed moderate populations of weevils. Diapause treatments were recommended to the growers by the Extension Service with about 50% responding with treatments. An economic population of weevils survived the winter of 1979-1980. This resulted in two of the four intensively sampled fields receiving a

total of 4.5 in-season treatments for boll weevil control plus an additional 5.5 treatments for bollworm control. This, combined with two diapause treatments applied to the other intensive fields, resulted in a marked increase in the number of insecticide treatments in 1980 over the previous 2 years.

Bollworm larval populations and boll damage: In the Evaluation Area, boll damage by bollworm was highest in 1977 when compared to 1978, 1979, and 1980 (figures 9-12). In 1977, bollworm damage occurred almost 2 weeks earlier than in 1978. The lowest level of damage was recorded in 1980. Insecticide treatments were effective in controlling bollworm populations in 1978, 1979, and 1980. Because of intense population pressure in late planted fields in 1977, economic damage often occurred.

In the Buffer Area, larval populations developed in early August in 1978 (Figure 13). Peak boll damage was recorded in some fields in late August and early September. However, excellent yields were produced within the Buffer Area in 1978. In 1979 and 1980, bollworm infestations were less intense in the Buffer Area than in 1978 (figures 14 and 15).

In Chowan County, approximately 15,000 damaged bolls per acre were observed in mid-August in 1977 (Figure 16). However, damage levels decreased rapidly with application of insecticides. Again in 1978, during late August, heavy bollworm infestations were observed (Figure 17). Excellent yields were recorded in spite of damage estimates of 15,000 bolls per acre. Similar damage levels were observed in 1979 (Figure 18). However, insecticide treatments were deliberately not applied to sampled fields in 1979. In 1980, damage levels reached an average of only 3,000 bolls per acre (Figure 19). Insecticide applications were also greatly reduced from previous years with only 1/3 of fields receiving treatments.

In Scotland-Robeson counties, sustained bollworm larval populations were

recorded during 1977 from early July until late September (Figure 20). Many fields sustained substantial yield loss to bollworms. In 1978, the bollworm infestation was much smaller than in 1977 (Figure 21). Infestations were much smaller in 1979 than in 1978 (Figure 22). In 1980, damage levels were above those in 1979 but still below 1977 and 1978 (Figure 23).

In Cleveland County, sizeable bollworm populations did not develop until mid-September during 1977 (Figure 24). Only low level populations developed in 1978 and 1979 (figures 25-26). However, in 1980, due in part to the application of several inseason treatments for boll weevil, beneficial insect populations were reduced allowing bollworm populations to reach damaging levels in some fields (Figure 27). Insecticides were not utilized for bollworm control in 1978 or 1979 in Cleveland County. In 1980, an average of 1.4 treatments were applied for bollworm control.

2. Beneficial insect populations in 1977 sampled fields and intensively sampled fields in 1978, 1979, and 1980

Estimated beneficial insect populations based on D-Vac samples in the 5 areas of North Carolina for 1977-1980 are presented in Figures 28-32. These estimates of beneficial arthropods include the total number of beneficial insects and spiders except for predaceous thrips. In the Evaluation Area (Figure 28) the population levels of total beneficials increased approximately 4-fold between 1977 and 1980. In 1977, average beneficial insect populations for July and August were estimated at 4,290 per acre; in 1978, 6,290 per acre; in 1979, 11,674 per acre; and in 1980, 17,070 per acre. Decline in beneficial insect populations in the Evalution Area during August is related to the initiation of insecticide treatments and the very hot and dry conditions that typically exist. During 1977, insecticide applications

were begun about July 30; in 1978, after August 15; in 1979, after August 8, and in 1980 about July 30. The decline in beneficial insect populations during late August and September of 1979 was less severe than in the two previous years. This may be a response not only to reduced insecticide treatments during that period but to an extended rainly period in early September which stimulated regrowth of plants making them more attractive to beneficial insect populations. The rapid decline in mid-August of 1980 was partially the result of the initiation of insecticide applications and partially due to the very hot and dry conditions that existed in the cotton fields.

An estimation of the total number of beneficial insects and spiders (except for predaceous thrips) in the Buffer Area is presented in Figure 29. Numbers of beneficial insects (not recorded in 1977), while not as high as in the Evaluation Area, increased in 1979 and 1980 when compared to 1978. More insecticide treatments were also applied in 1978 than in the following 2 years. The average number of beneficial insects per acre during July and August was 3,608 in 1978; 11,393 in 1979; and 13,806 in 1980. The seasonal decline in beneficial insects in the Buffer Area was directly related to initiation of insecticide treatments in all 3 years.

An estimation of the total number of beneficial insects and spiders (except for predaceous thrips) in Chowan County is presented in Figure 30. An extremely heavy Heliothis population in 1977 required the intensive use of insecticides during August to protect the crop, resulting in a rapid decline of beneficial arthropods in August. In 1978, an average of 11.75 insecticide treatments were applied to the crop. However, 5 of these were early season treatments with diflubenzuron followed by an application of azinphosmethyl on ca. July 20. As shown, the beneficial arthropods seemed to recover rather

quickly following this single organophosphate insecticide treatment. The remaining 5.75 treatments were initiated after August 15 and caused a sharp decline in beneficial insect numbers. In 1977, peak beneficial insect populations developed earlier than in 1978; however, peak numbers were similar both years. In 1979 and 1980, intensively sampled fields were not treated with insecticides, and large beneficial insect populations were present from early July until mid-September. The average number of beneficial insects per acre during July and August was 9,432 in 1977; 6,181 in 1978; 20,103 in 1979, and 18,227 in 1980.

The total number of beneficial insects and spiders (except predaceous thrips) in Scotland and Robeson counties is shown in Figure 31. The numbers of beneficial arthropods were lowest in Scotland and Robeson counties of all the areas sampled. Populations declined rapidly as insecticide treatments were initiated. The average number of beneficials per acre for July and August was 799 in 1977; 4,353 in 1978; 4,930 in 1979; and 9,990 in 1980.

An estimate of the total number of beneficial arthropods (except predaceous thrips) in Cleveland County is shown in Figure 32. Of the areas sampled, Cleveland County had the largest populations of beneficial insects and spiders. While there was a decline in numbers during September, large numbers were present throughout the sampling period, June through mid-September. Numbers were lowest in 1977, an extreme dry crop season. The average number of beneficial insects per acre during July and August was 6,208 in 1977; 15,148 in 1978; 14,559 in 1979, and 24,515 in 1980. There was low usage of insecticides all 3 years of the Trial.

3. Comparison of estimated yields in sampled fields with actual area-wide harvested yields during 1977, 1978, 1979, and 1980

Estimated yields in fields sampled in 1977-1980, as well as actual

reported yields for 1977-1979, are shown in Table 7. As expected, yields varied considerably from field to field, but trends within areas are evident. The excellent yields recorded in 1978 reflect the highly favorable weather which occurred during most of the growing season.

4. Use of insecticides in sampled fields in 1977, 1978, 1979, and 1980

Insecticides applied in the BWE Trial Area and the two CIC-practice areas in North Carolina are shown in Table 8. Because of the very hot, dry weather in 1977, the growing season was shortened by several weeks and several additional insecticide treatments. In some cases, growers stopped treating because of marginal crop conditions.

Evaluation Area: The number of insecticide treatments applied in all sampled fields for bollworm control in 1978 was less than observed in intensive fields only (Table 9). However, the total number of treatments for boll weevil and bollworm control in 1978 was similar for both groups of fields, with an average of 9.9 insecticide treatments applied in all sampled fields. This was reduced to 2.5 in 1979 and to 1.2 in 1980.

Buffer Area: During 1978, an average of 13 insecticide treatments were applied in the intensively sampled fields (Table 9), while an average of 12 treatments were applied in all fields sampled (Table 8). In 1979, 12.8 treatments were applied in intensively sampled fields, while an average of 12.9 treatments were applied in all fields sampled in the Buffer Area. In 1980, the applications dropped to approximately 9 in all sampled fields as well as the 4 intensive fields.

Chowan County: As explained above, this was a Methods Development Area for the APHIS operational group. Bollworms received an average of 5.8 insecticide treatments in the intensively sampled fields during 1978, while an average of 4 treatments were applied for bollworm control in all fields

sampled. The APHIS operational group used cotton fields in Chowan County to test the efficacy of microbial insecticides against the bollworm in 1979 and 1980. Intensively sampled fields in 1979 represented the untreated check, while all fields sampled represented the total treatments included in the large-scale field experiment. Under these experimental conditions, 4.6 applications were applied for bollworm control. In 1980, only 1/3 of the fields required treatments for bollworm control. The 4 intensively sampled fields received zero treatments, and all sampled fields received an average of 0.64 applications.

Scotland and Robeson counties: An average of 10.8 treatments were applied in intensively sampled fields in 1978, while an average of 9.4 treatments were applied to all fields sampled. In 1979, an average of 7.5 and 7.8 insecticide treatments were applied to intensively sampled and all fields sampled, respectively. Insecticides applied during August of 1979 were for boll weevil suppression as well as for bollworm control. In 1980, an average of 9.5 treatments were applied in intensively sampled fields and 8.3 applications in all fields sampled. A 3-4 fold increase in treatments for boll weevil occurred in 1980 compared to 1979.

Cleveland County: One grower applied a single application of methomyl for bollworm control during September 1977. No insecticides were applied in 1978. During 1979, no insecticides were applied by growers for bollworm or for inseason control of boll weevils. However, ten fields out of twenty did receive boll weevil diapause treatments in combination with defoliant. In 1980, at least 4 of 21 fields received inseason control for boll weevil with 7 of the 21 fields receiving treatments for bollworm. Fourteen of twenty-one fields received boll weevil diapause control in conjunction with defoliation. Total insecticide treatments in 1980 increased 4-fold over 1979 (Table 9).

Table 7.--Estimated yield (lbs. lint per acre) in cotton fields sampled for Biological Evaluation of the Boll Weevil Trial as well as grower harvested yields, North Carolina, 1977, 1978, 1979, and 1980.

	Sampled fields1/			Avg. areawide harvested yields2/
Year	No. of fields	Lbs. avg.	Lint/acre range	Lbs. lint/acre
			Evaluation Area3/	
1977	18	567	207- 923	389
1978	124	691	255-1075	611
1979	114	499	183- 822	374
1980	68	415	226- 861	6/
			Buffer Area4/	
1977		5/	-	333
1978	35	923	75-1225	639
1979	18	727	333-1075	506
1980	20	624	360- 862	6/
			Chowan County	
1977	5	473	307- 671	331
1978	18	740	541- 964	600
1979	24	549	216- 699	485
1980	25	510	297- 851	6/
			Scotland-Robeson Counties	
1977	5	229	129- 312	255
1978	19	664	194-1069	450
1979	16	478	363- 546	523
1980	20	483	116-1021	6/
			Cleveland County	
1977	8	293	66- 520	161
1978	20	516	205- 807	361
1979	18	320	192- 403	385
1980	21	319	157- 446	6/

1/ Each field with 12 samples of 5 row-feet.
2/ Agricultural Statistics, N. C. Crop and Livestock Reporting Service. September 1980.
3/ Includes Bertie, Chowan, Edgecombe, Halifax, Hertford, Martin, Nash and Northampton counties.
4/ Includes Beaufort, Johnston, Pitt, Wilson, Cumberland, Harnett and Sampson counties.
5/ Fields not sampled in the Buffer Area in 1977.
6/ Not available until the summer of 1981.

Table 8.--Use of insecticides in fields sampled in North Carolina, BWET, 1977, 1978, 1979, and 1980.

Year	No. of fields	Avg. no of appl. for Boll weevil	Avg. no of appl. for Boll-worm	Average no. of lbs. of indicated insecticide/acre: Diflubenzuron	B. t.	Phosphate	Methomyl	Pyrethroid	Chlordimeform	Toxaphene	NVP
						Evaluation Area					
1977	18	.4	7.7	0	0	8.5	.12	.03	0	10.8	0
1978	122	6.2	3.7	0	0	8.8	.12	.13	.02	2.9	0
1979	114	.4	2.1	.02	0	.1	.03	.20	.03	.1	0
1980	68	0	1.2	0	0	0	0	.12	.01	0	0
						Buffer Area					
1977	-	-	-	-	-	-	-	-	-	-	-
1978	34	.7	11.3	0	0	10.4	.93	.11	.12	6.5	0
1979	18	5.1	7.8	.02	.56	1.9	0	.55	.50	0	0
1980	21	4.3	4.4	0	0	1.2	0	.37	.36	0	0
						Chowan County					
1977	5	8.0	2.2	.35	.80	1.4	0	0	0	.4	0
1978	19	6.0	4.0	.24	0	4.5	.16	0	0	8.0	0
1979	27	0	4.6	0	.59	.1	0	.12	.29	0	.20
1980	25	0	.64	0	.21	.07 1/	0	.004	0	.02 1/	.005
						Scotland-Robeson Counties					
1977	5	0	11.6	0	0	10.4	.43	.10	0	7.4	0
1978	16	0	9.4	0	0	3.6	.51	.48	.13	4.3	0
1979	21	.7	7.1	0	0	2.8	0	.50	.32	2.0	0
1980	20	2.0	6.3	0	0	1.9	.10	.55	.08	.48	0
						Cleveland County					
1977	8	0	.1	0	0	0	.03	0	0	0	0
1978	20	0	0	0	.0	0	0	0	0	0	0
1979	20	.5	0	0	0	.16	0	0	.0	0	0
1980	21	1.2	.83	0	0	.73	.01	.07	.06	.45	0

1/ Experimental or spider mite applications (not included in average bollworm applications).

Table 9.--Use of insecticides in base-line fields sampled in North Carolina, BWET, 1977 and intensively sampled fields in 1978, 1979, and 1980.

		Avg. no. of appl. for		% appl.	Average no. of lbs. of indicated insecticide/acre						
Year	No. of fields	Boll weevil	Boll-worm	by aircraft	Diflubenzuron	B. t.	Phosphate	Methomyl	Pyrethroid	Chlordimeform	Toxaphene
					Evaluation Area						
1977	18	.4	7.7	94	0	0	8.5	.12	.03	0	10.8
1978	8	5.6	5.2	100	0	0	8.4	.09	.12	.06	1.3
1979	10	0	1.8	100	0	0	0	0	.22	0	0
1980	8	0	1.5	100	0	0	0	0	.15	0	0
					Buffer Area						
1977	-	-	-	-	-	-	-	-	-	-	-
1978	4	.8	12.2	92	0	0	5.7	1.18	.14	.13	5.0
1979	4	5.3	7.5	100	.06	.56	1.3	0	.53	.44	0
1980	4	4.0	5.0	50	0	0	1.1	0	.42	.38	0
					Chowan County						
1977	5	8.0	2.2	92	.35	.80	1.4	0	0	0	.4
1978	4	6.0	5.8	47	.31	0	5.7	.11	0	0	10.4
1979	4	0	0	0	0	0	0	0	0	0	0
1980	4	0	0	0	0	0	0	0	0	0	0
					Scotland-Robeson Counties						
1977	5	0	11.6	88	0	0	10.4	.43	.10	0	7.4
1978	4	0	10.8	93	0	0	3.9	.55	.54	.13	2.3
1979	4	.25	7.3	93	0	0	2.5	0	.48	.39	2.1
1980	4	1.5	8.0	53	0	0	.61	0	.68	.13	.88
					Cleveland County						
1977	8	0	.13	0	0	0	0	.03	0	0	0
1978	4	0	0	0	0	0	0	0	0	0	0
1979	4	.75	0	0	0	0	.19	0	0	0	0
1980	4	1.6	1.4	0	0	0	.78	0	.14	1.7	1.4

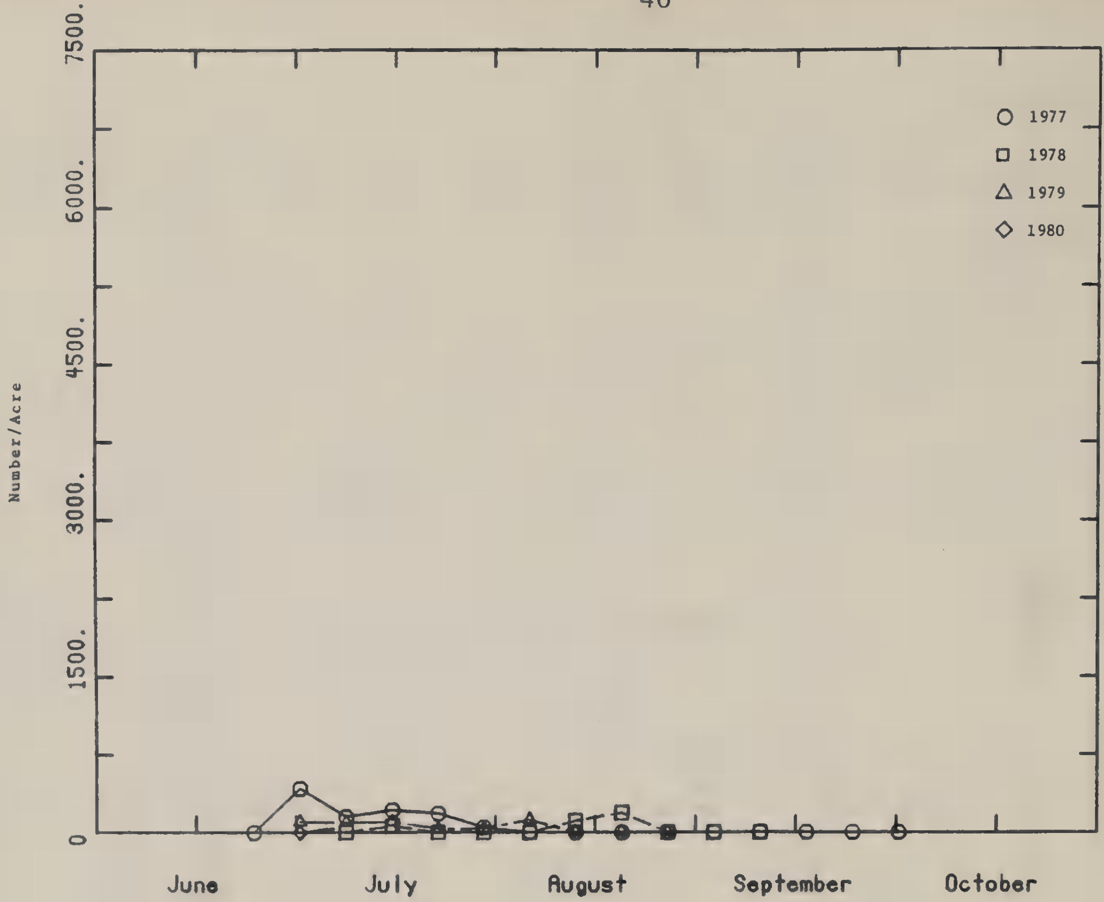


Figure 4. Estimated no. of boll weevil punctures (feeding and oviposition) in 1977 fields and in 1978, 1979 and 1980 intensive fields in Evaluation Area, BWET. North Carolina.

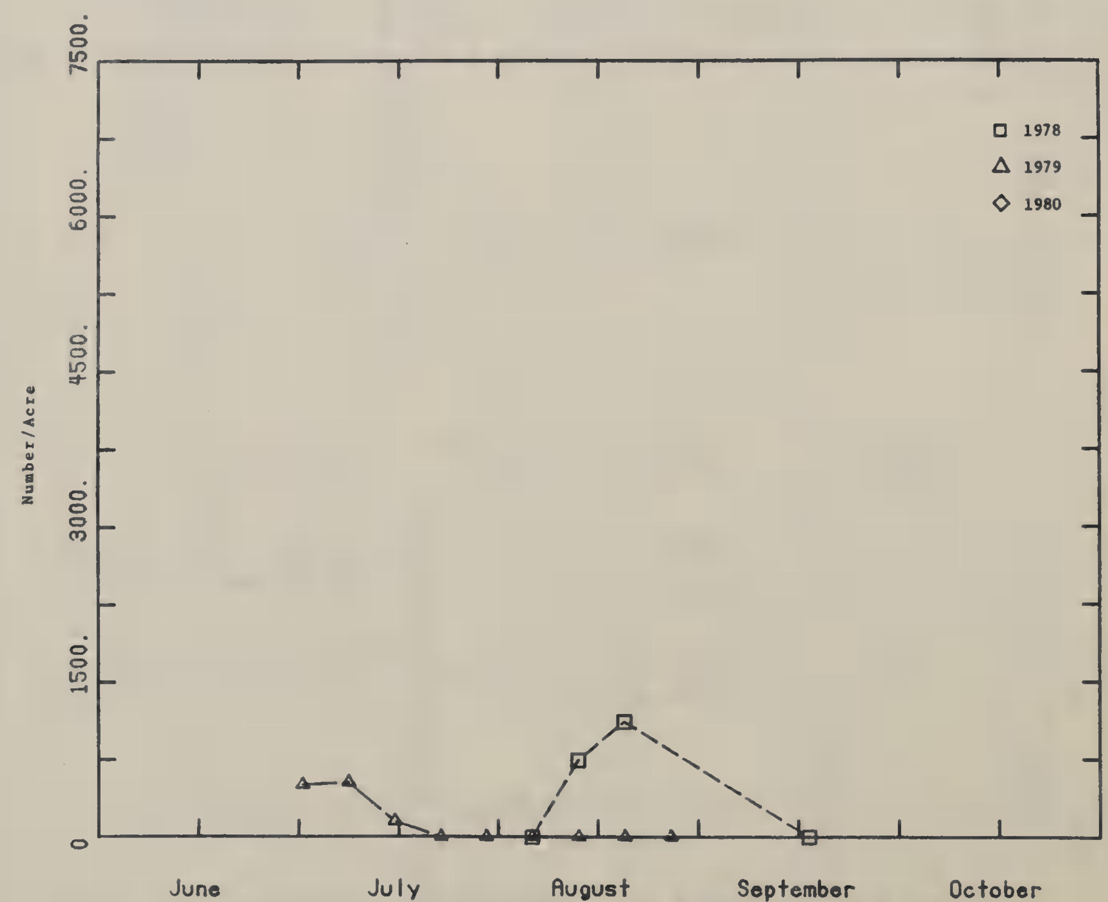


Figure 5. Estimated no. of boll weevil punctures (feeding and oviposition) in 1978, 1979 and 1980 intensive fields in Buffer Area, BWET. North Carolina.

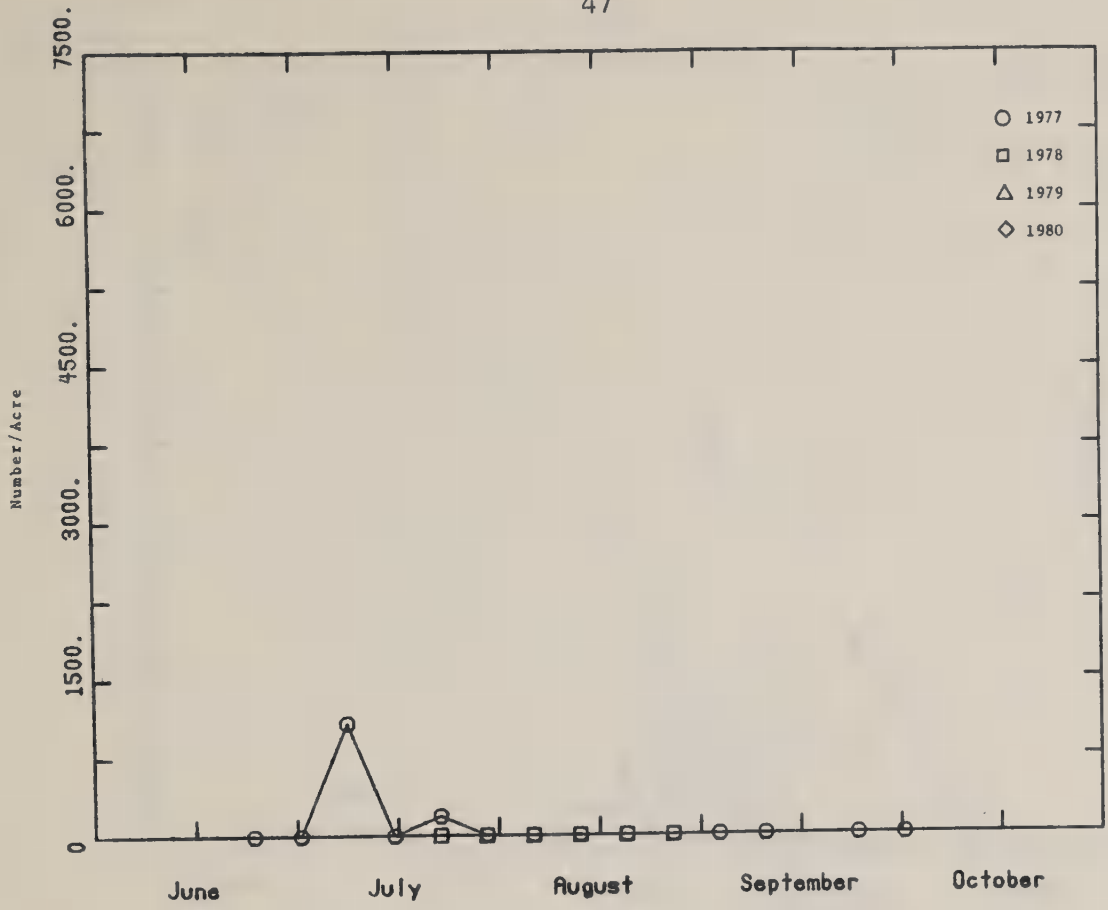


Figure 6. Estimated no. of boll weevil punctures (feeding and oviposition) in 1977 fields and in 1978, 1979 and 1980 intensive fields in Chowan County, BWET. North Carolina.

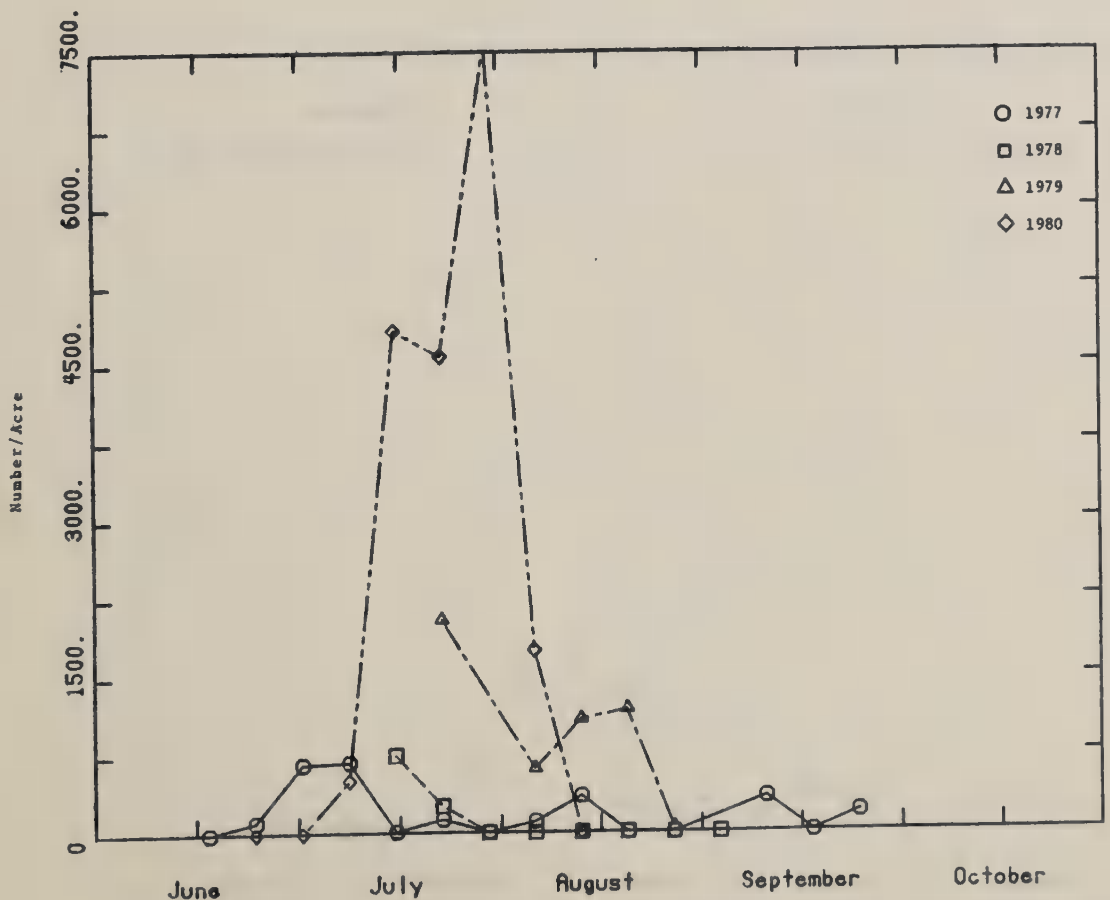


Figure 7. Estimated no. of boll weevil punctures (feeding and oviposition) in 1977 fields and in 1978, 1979 and 1980 intensive fields in Scotland-Robeson counties outside BWET area. North Carolina.

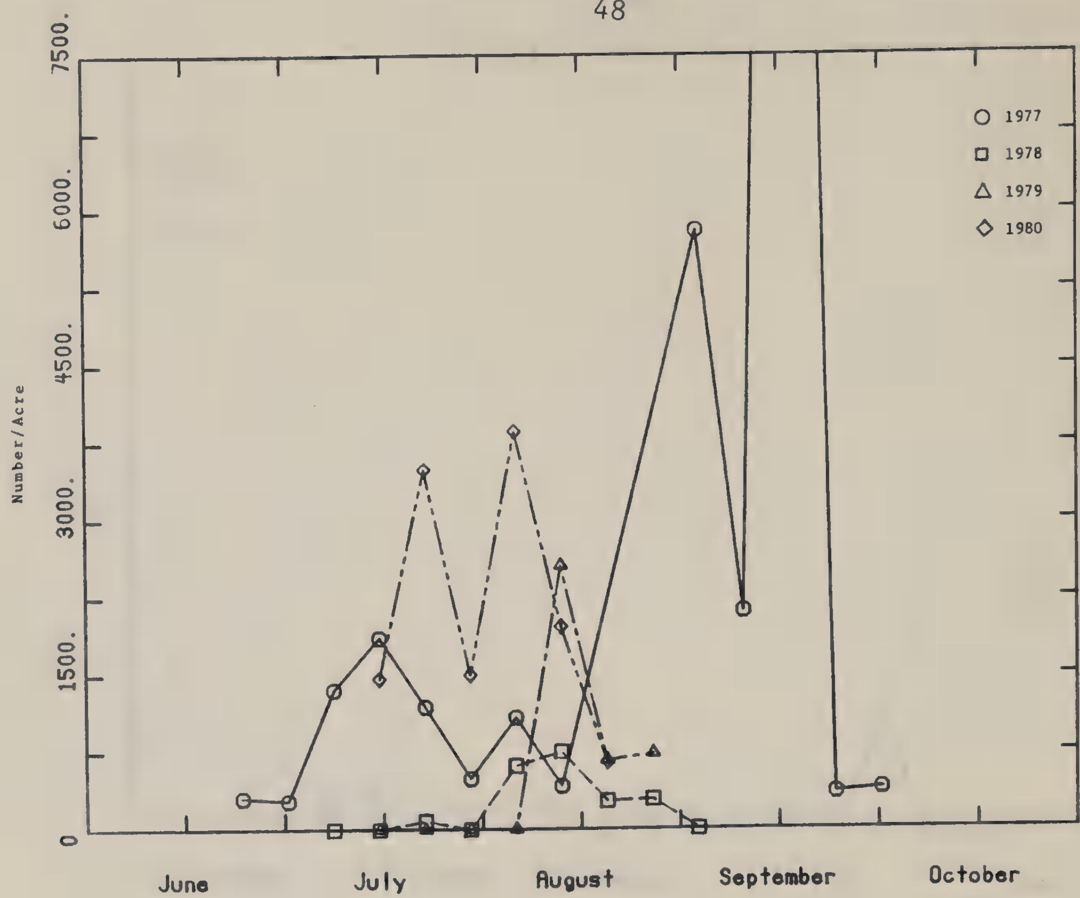


Figure 8. Estimated no. of boll weevil punctures (feeding and oviposition) in 1977 fields and in 1978, 1979 and 1980 intensive fields in Cleveland County outside BWET area. North Carolina.

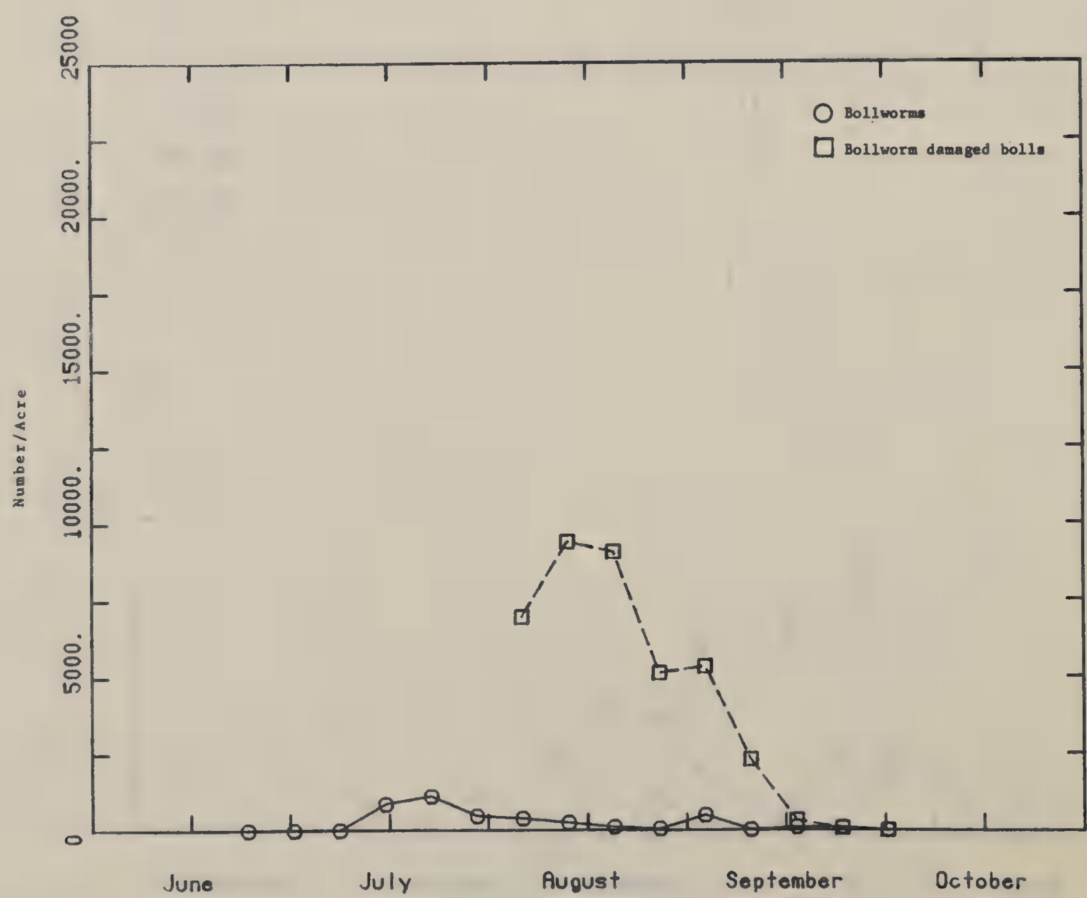


Figure 9. Estimated no. of bollworm larvae and no. of bollworm damaged bolls per acre in sampled fields in the Evaluation Area, BWET. North Carolina. 1977.

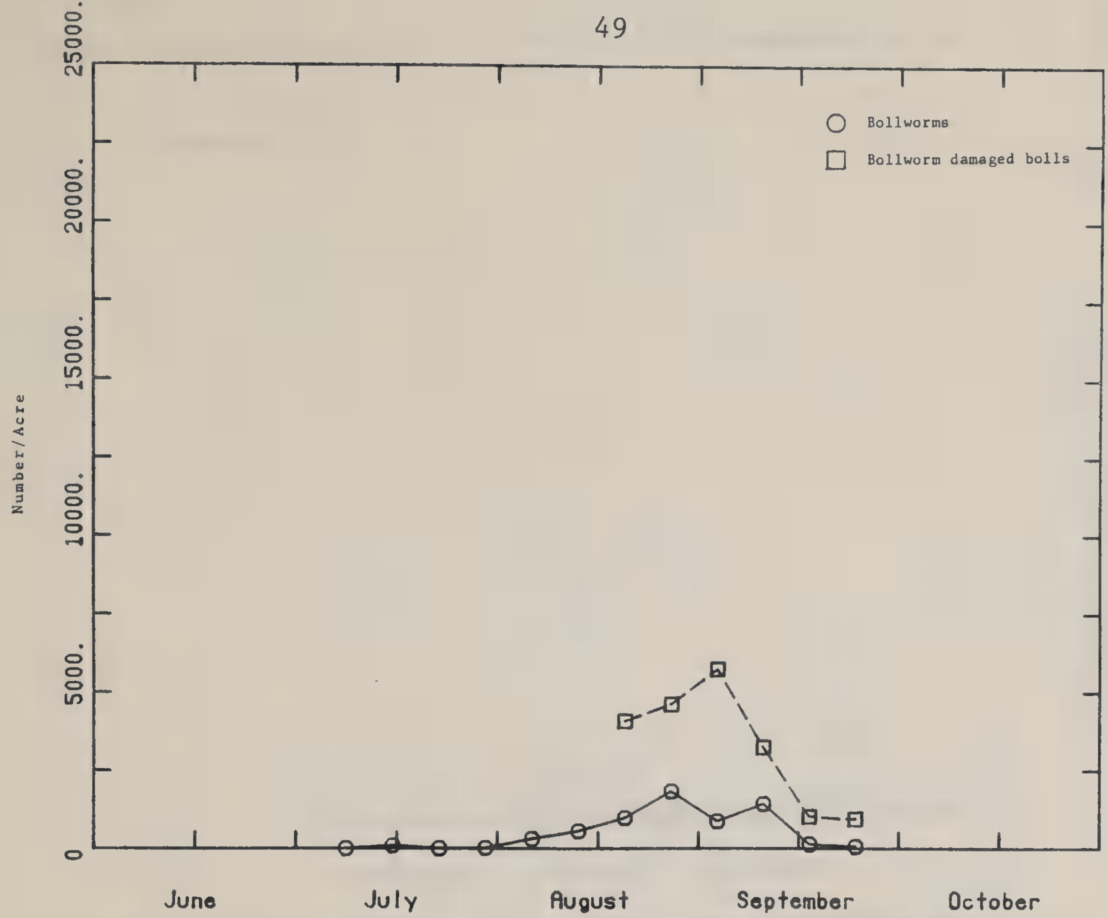


Figure 10. Estimated no. of bollworm larvae and no. of bollworm damaged bolls per acre in sampled fields in the Evaluation Area, BWET. North Carolina. 1978.

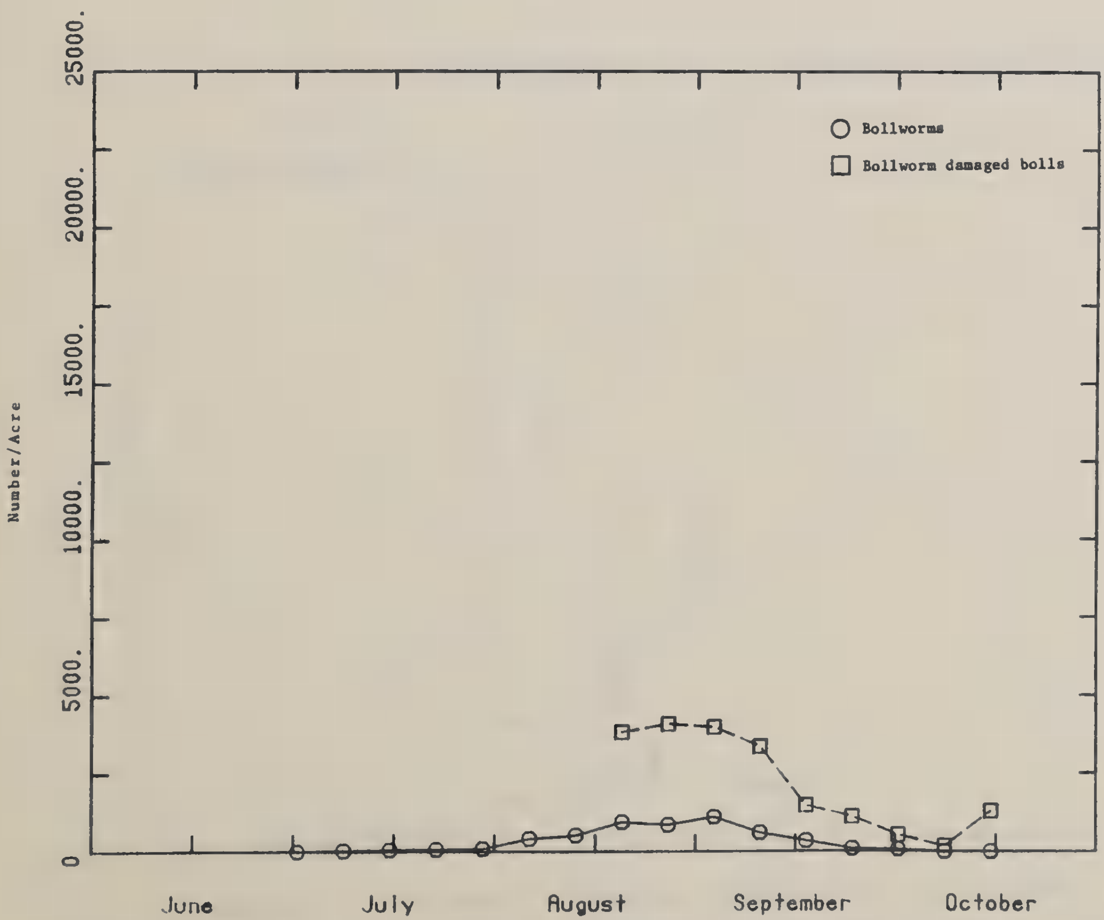


Figure 11. Estimated no. of bollworm larvae and no. of bollworm damaged bolls per acre in intensively sampled fields in the Evaluation Area, BWET. North Carolina. 1979.

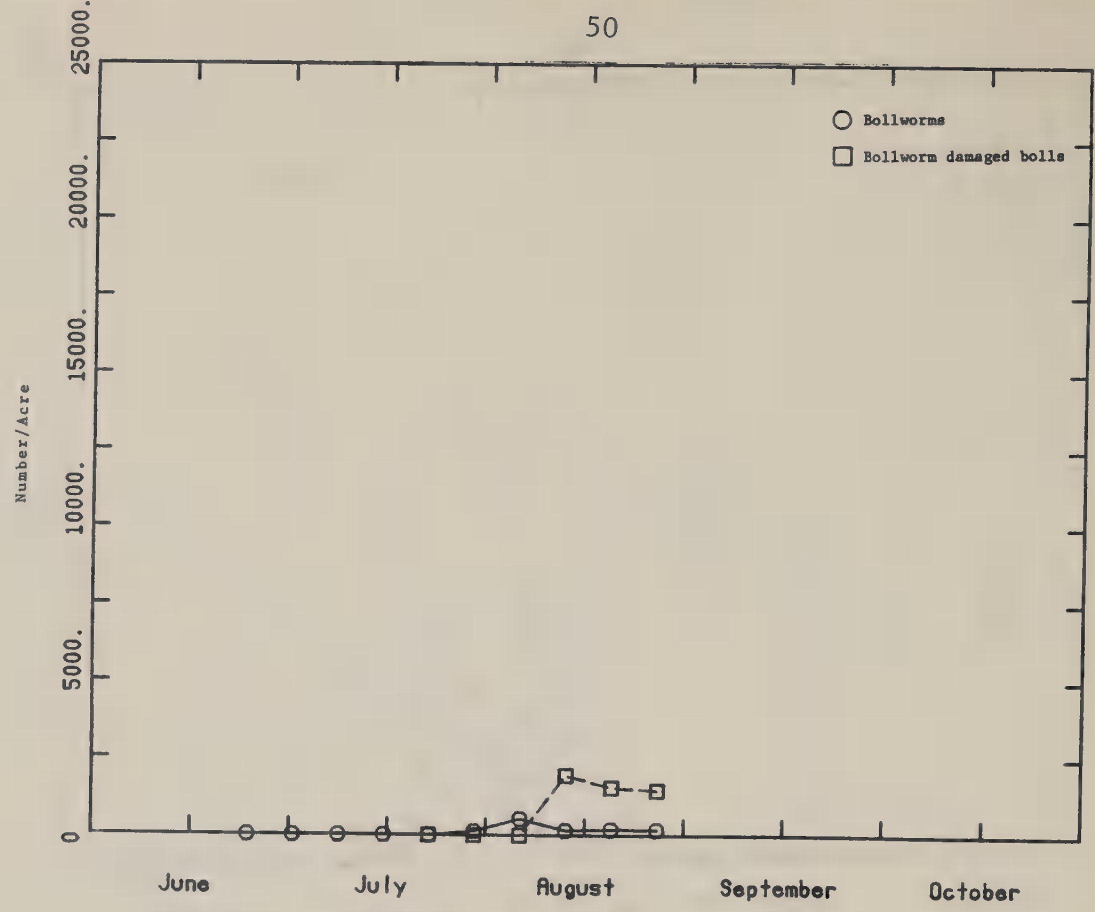


Figure 12. Estimated no. of bollworm larvae and no. of bollworm damaged bolls per acre in sampled fields in the Evaluation Area, BWET. North Carolina. 1980.

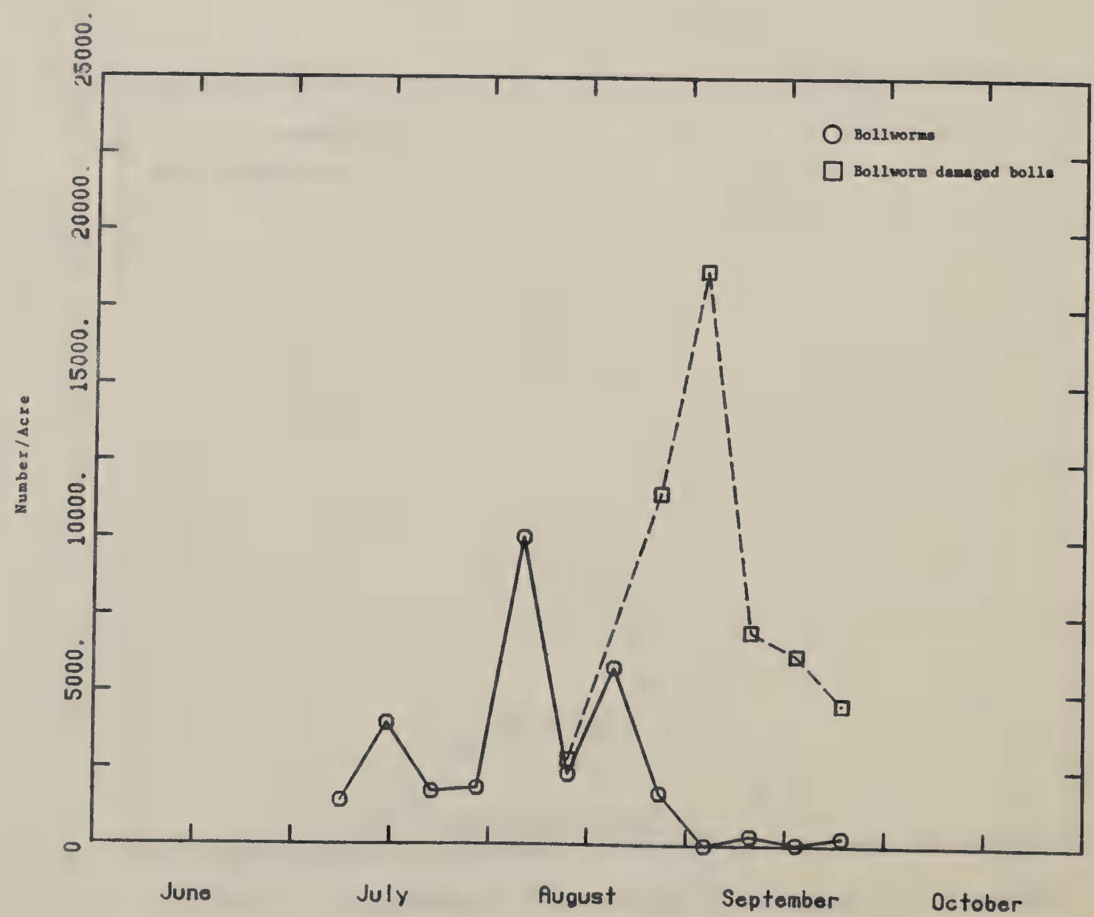


Figure 13. Estimated no. of bollworms and bollworm damaged bolls per acre in intensively sampled field in the Buffer Area, BWET. North Carolina. 1978.

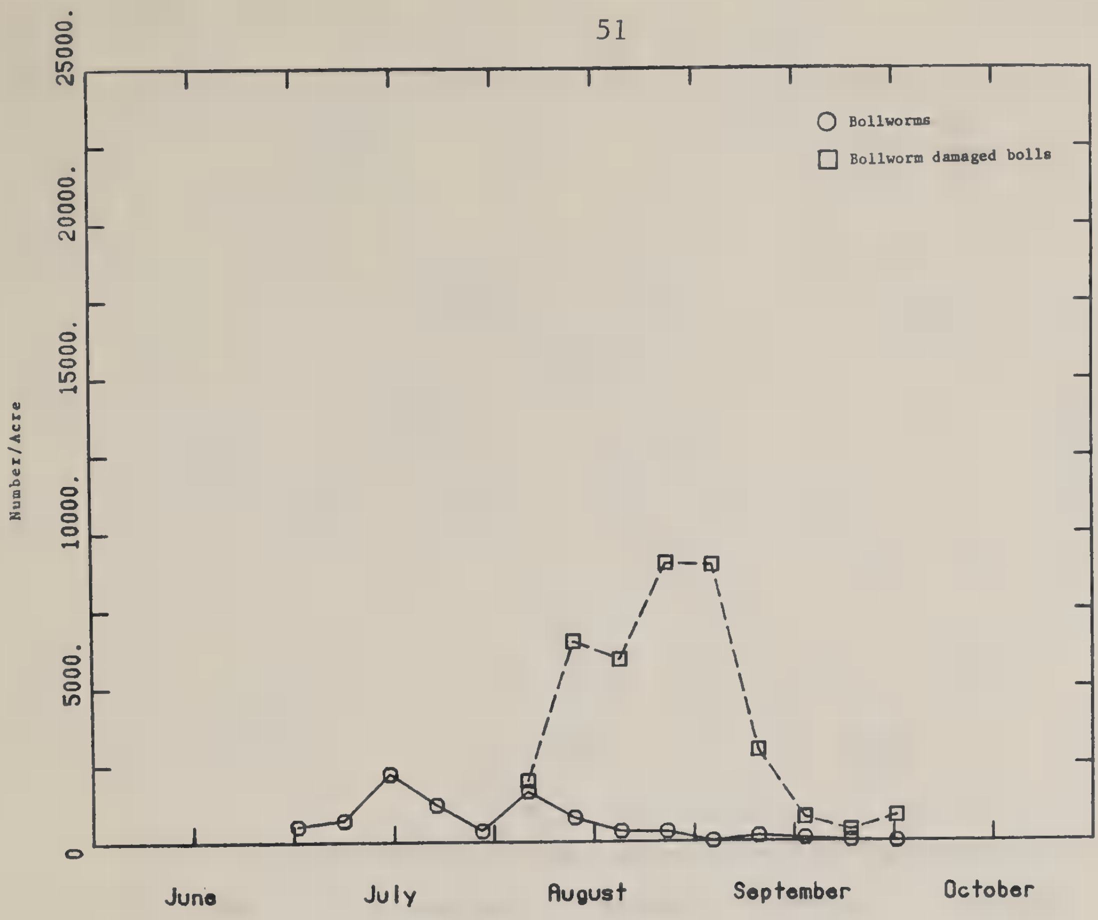


Figure 14. Estimated no. of bollworms and bollworm damaged bolls per acre in intensively sampled fields in the Buffer Area, BWET. North Carolina. 1979.

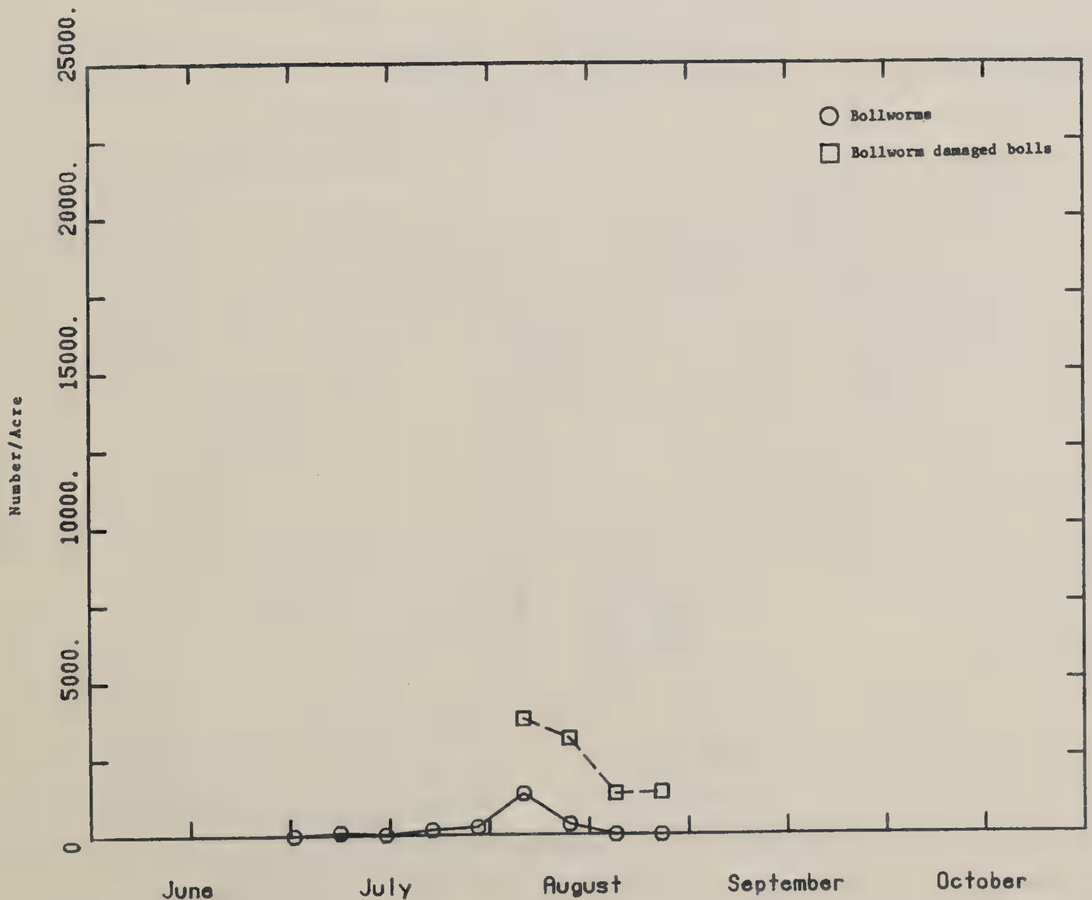


Figure 15. Estimated no. of bollworms and bollworm damaged bolls per acre in intensively sampled field in the Buffer Area, BWET. North Carolina. 1980.

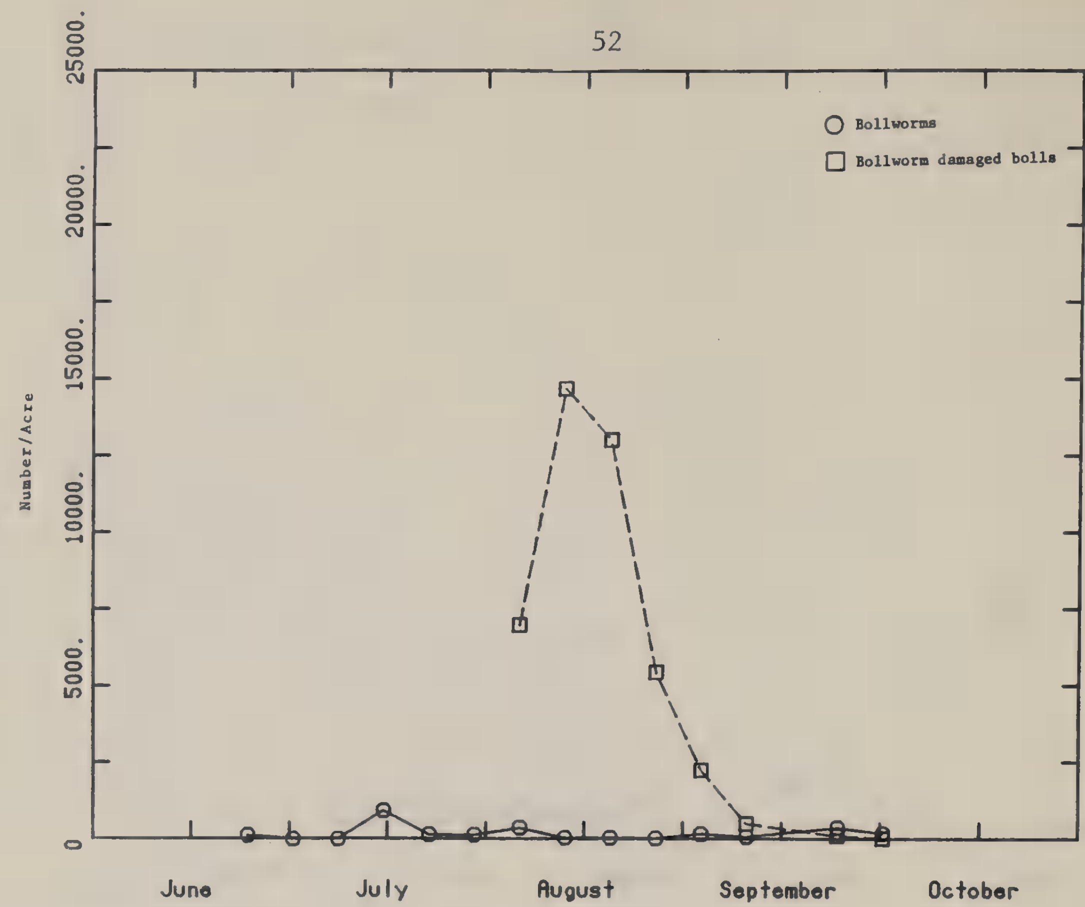


Figure 16. Estimated no. of bollworms and bollworm damaged bolls per acre in sample fields in Chowan County, BWET. North Carolina. 1977.

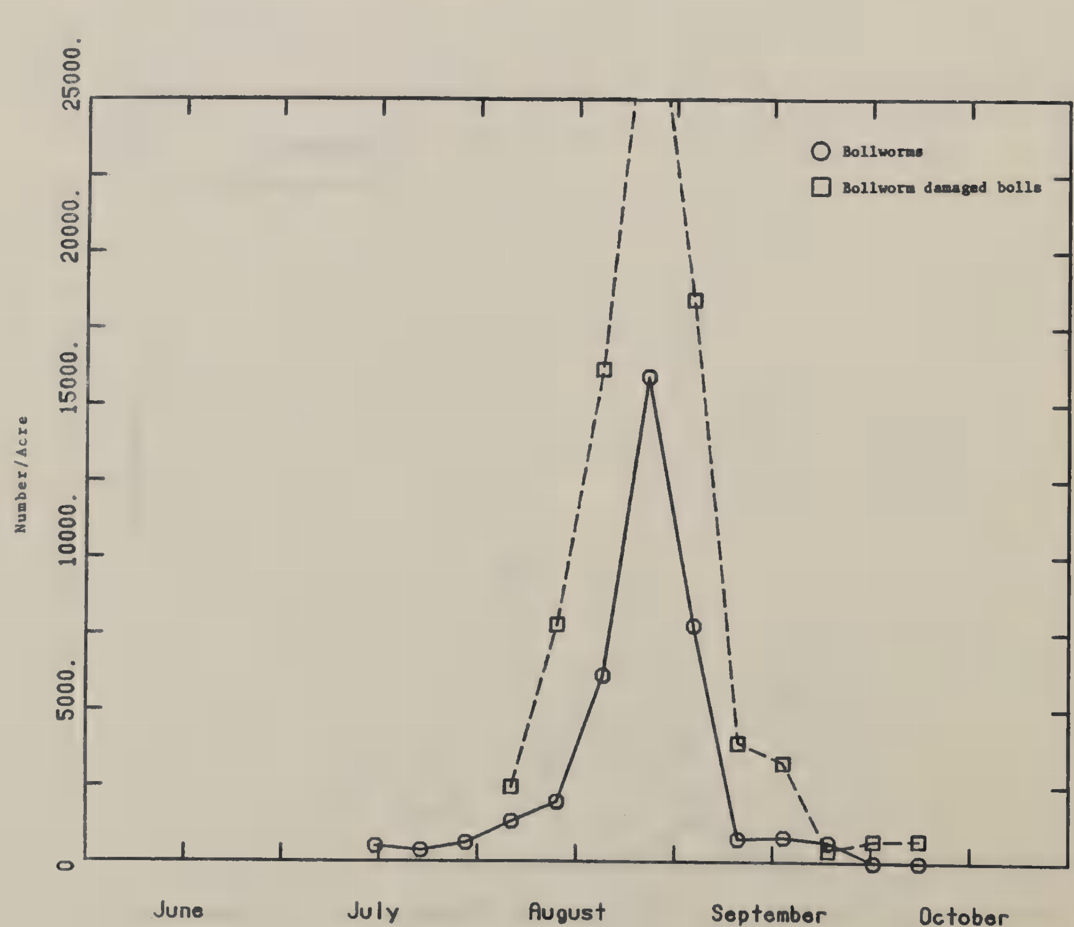


Figure 17. Estimated no. of bollworms and bollworm damaged bolls per acre in intensively sampled fields in Chowan County, BWET. North Carolina. 1978.

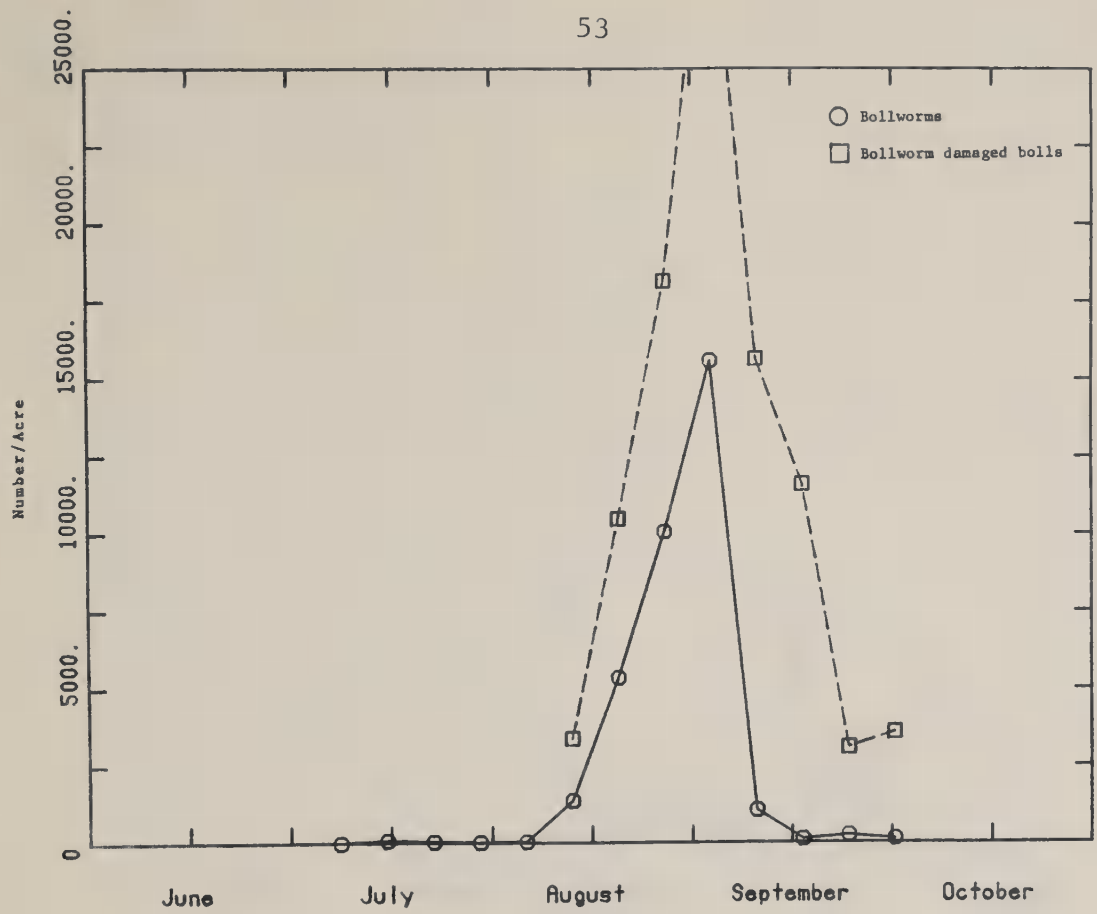


Figure 18. Estimated no. of bollworms and bollworm damaged bolls per acre in intensively sampled fields in Chowan County, BWET. North Carolina. 1979.

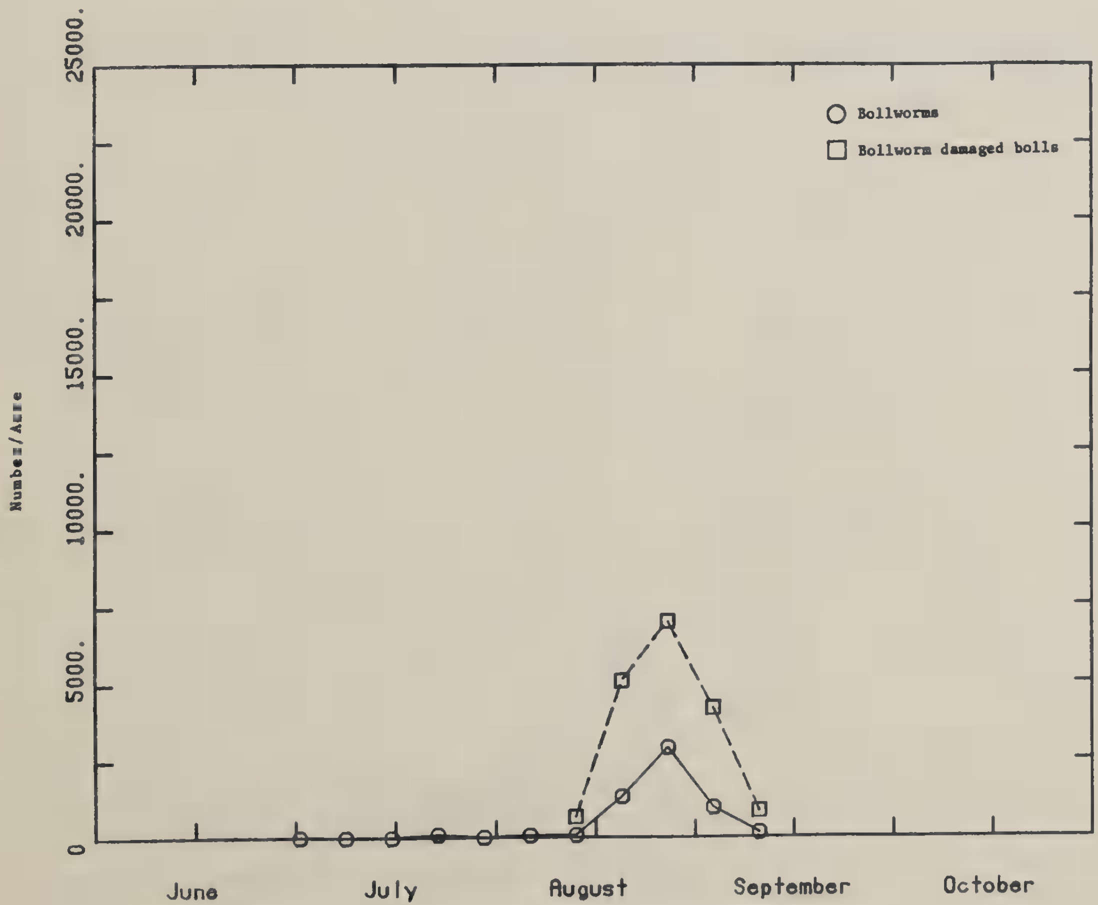


Figure 19. Estimated no. of bollworms and bollworm damaged bolls per acre in intensively sampled fields in Chowan County, BWET. North Carolina. 1980.

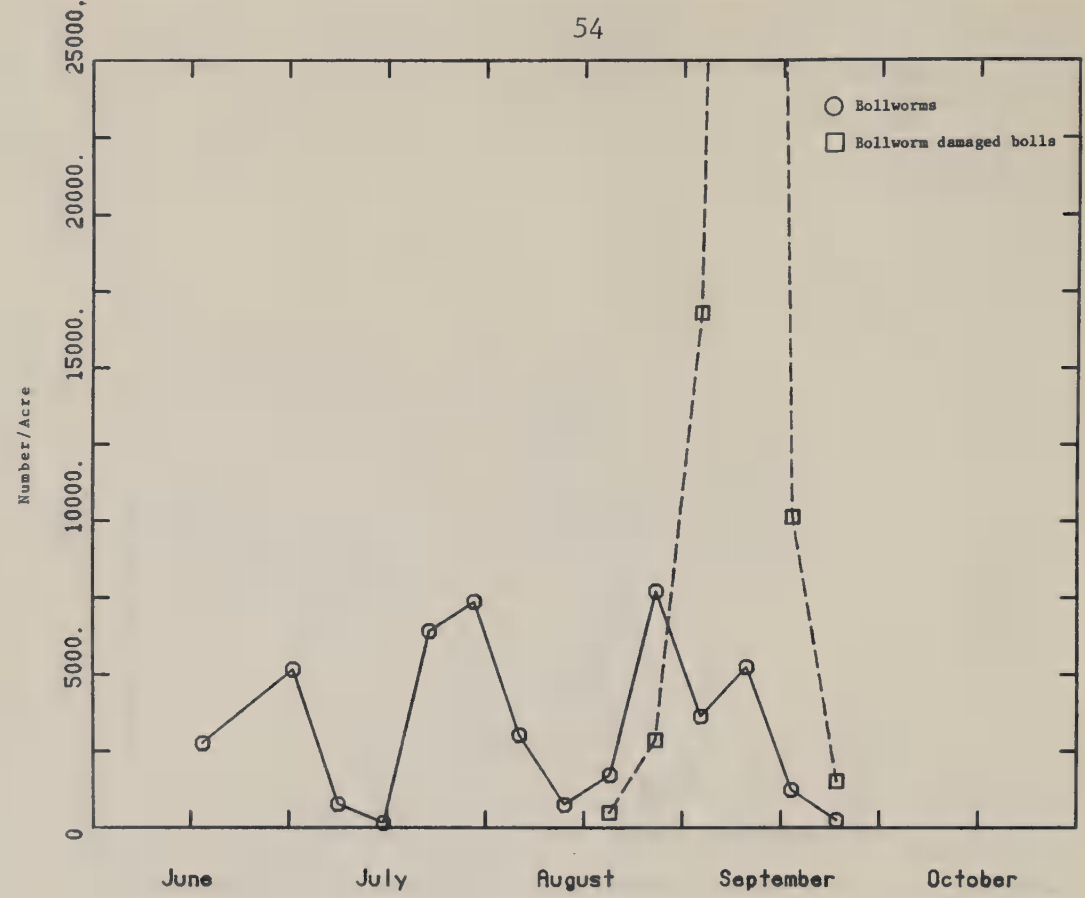


Figure 20. Estimated no. of bollworm larvae and bollworm damaged bolls per acre in sampled fields in Scotland-Robeson counties outside BWET area. North Carolina. 1977.

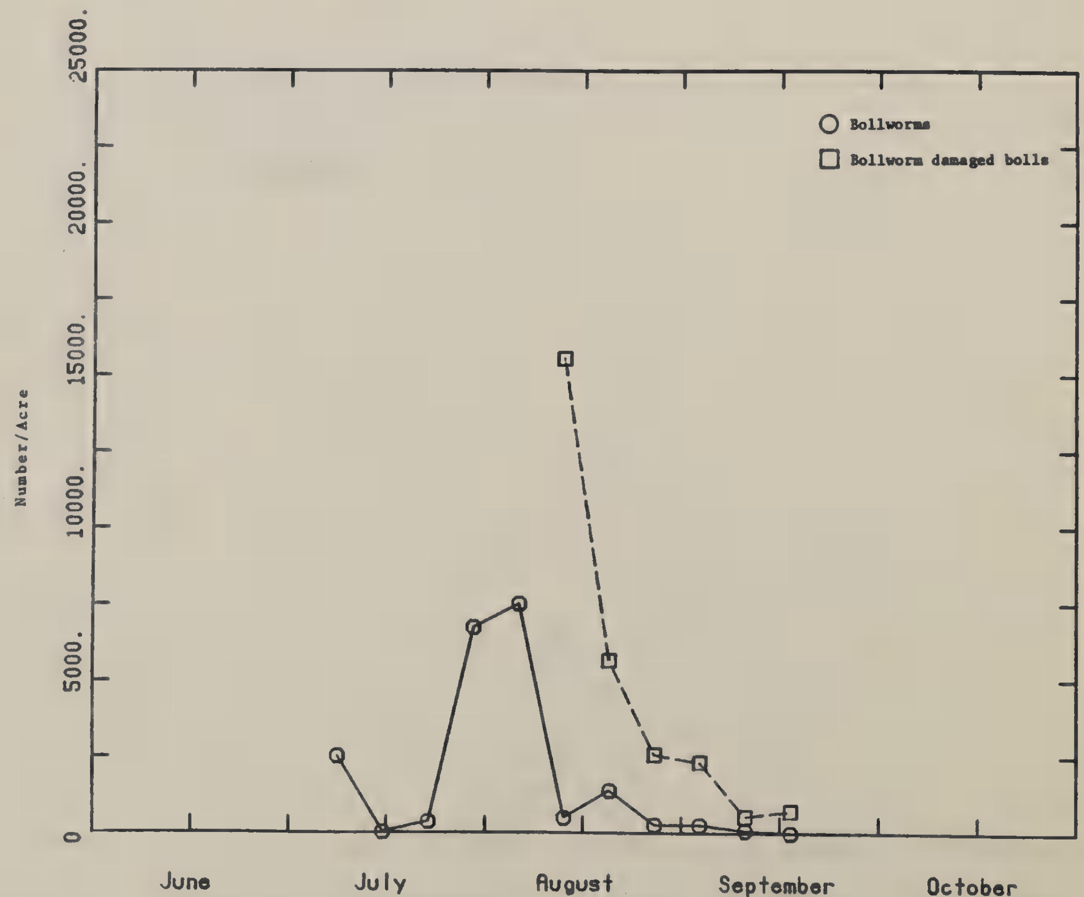


Figure 21. Estimated no. of bollworm larvae and bollworm damaged bolls per acre in intensively sampled fields in Scotland-Robeson counties outside BWET area. North Carolina. 1978.

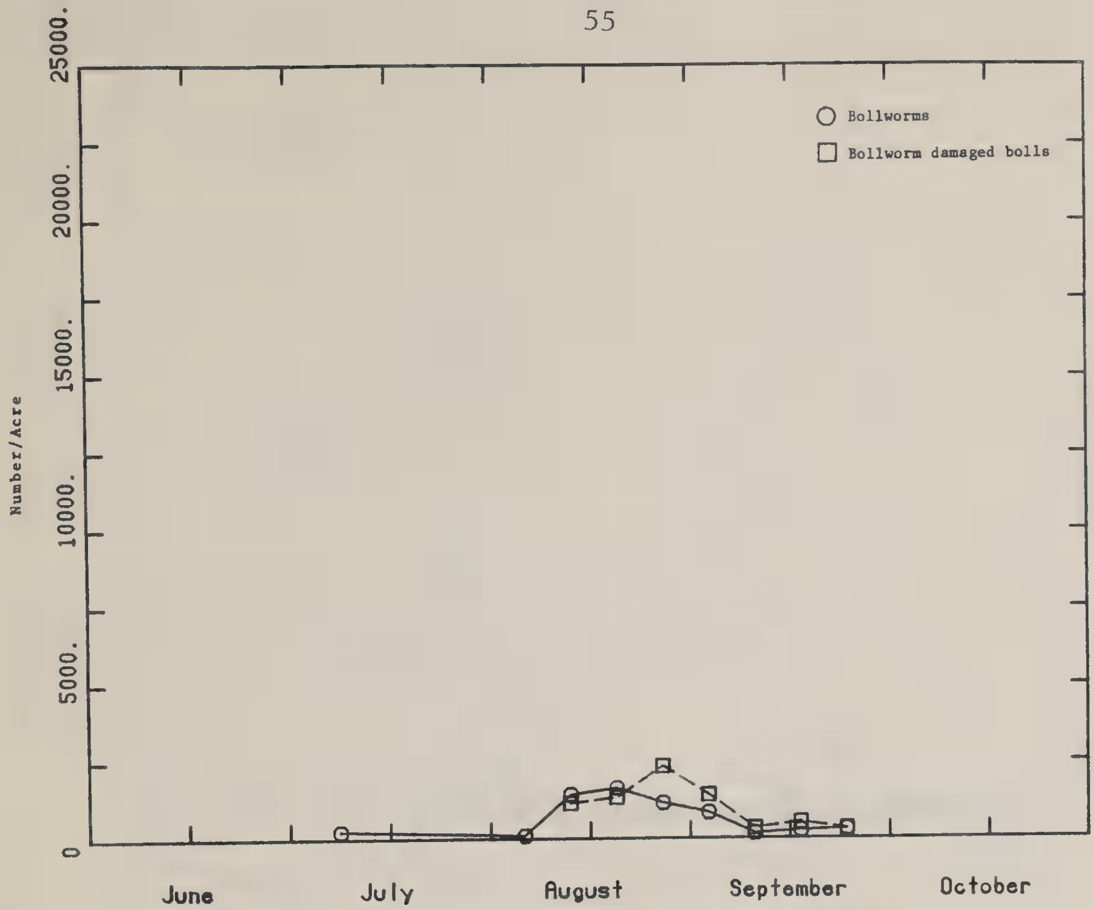


Figure 22. Estimated no. of bollworm larvae and bollworm damaged bolls per acre in intensively sampled fields in Scotland-Robeson counties outside BWET area. North Carolina. 1979.

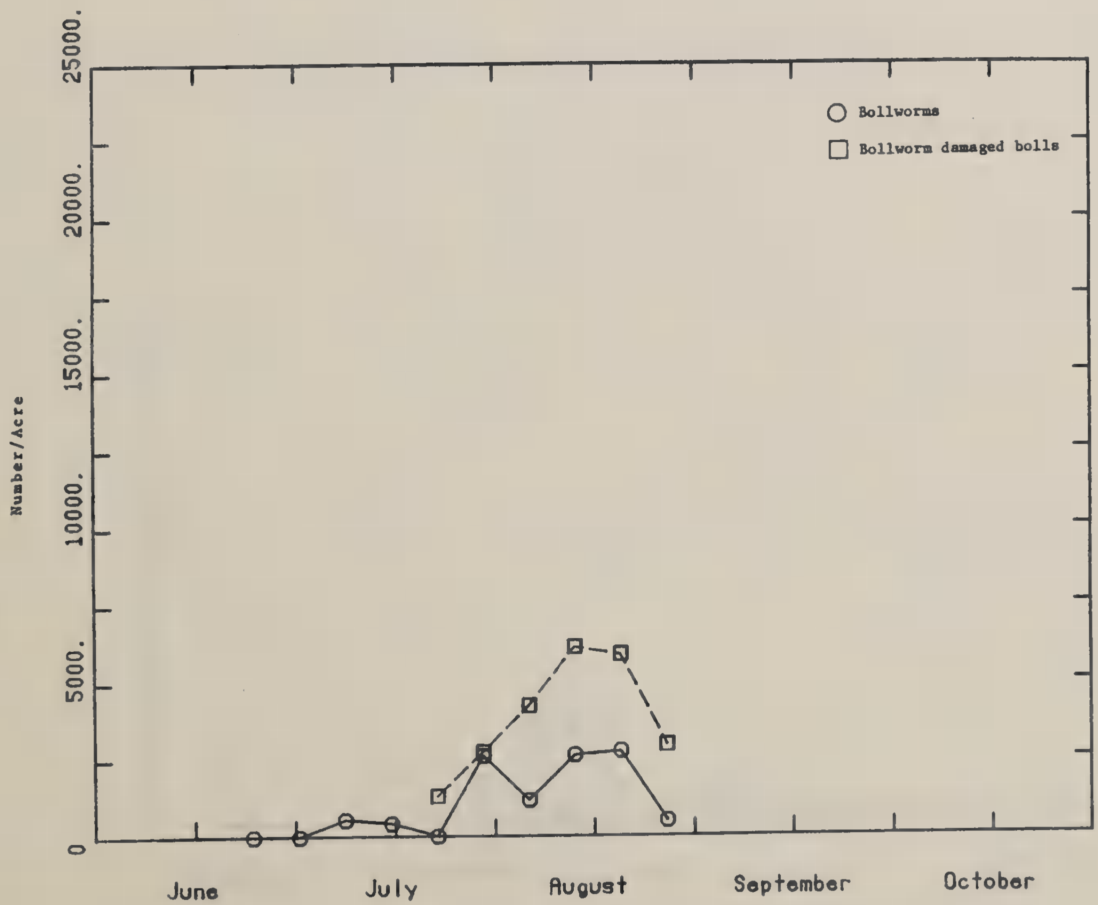


Figure 23. Estimated no. of bollworm larvae and bollworm damaged bolls per acre in intensively sampled fields in Scotland-Robeson counties outside BWET area. North Carolina. 1980.

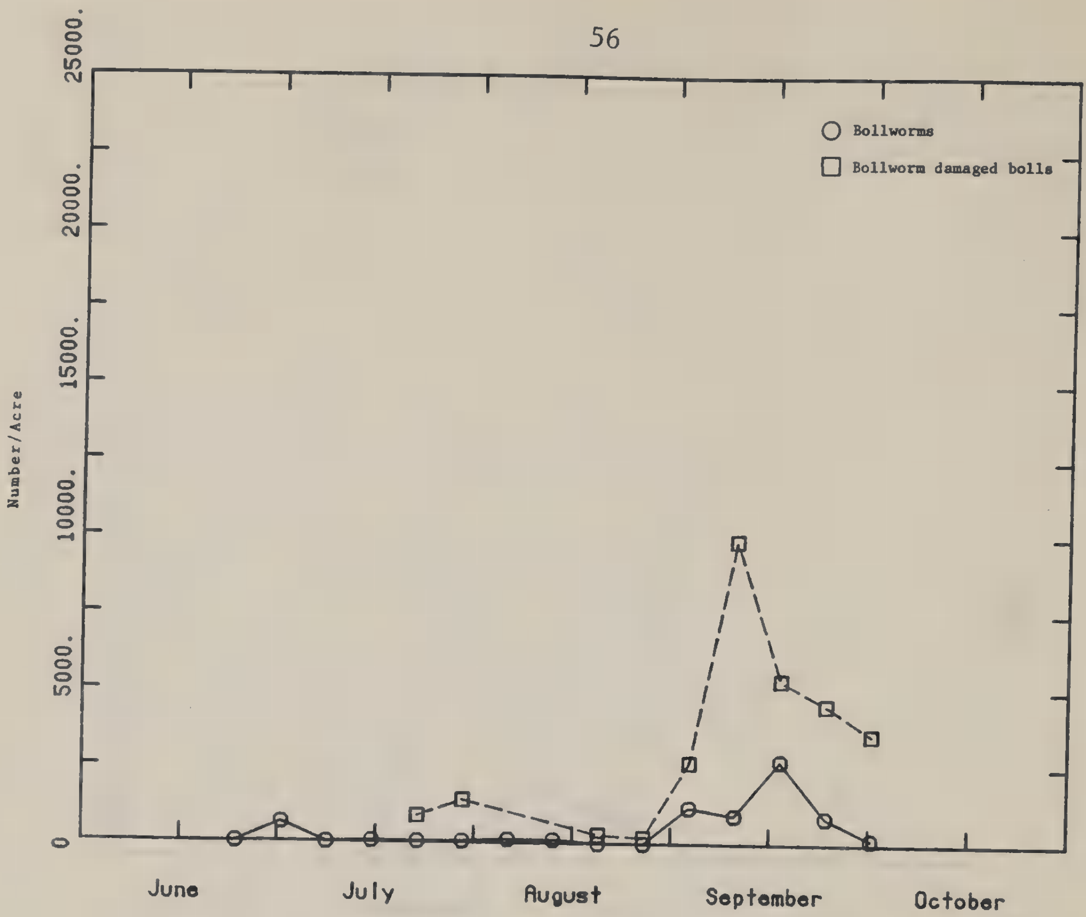


Figure 24. Estimated no. of bollworm larvae and bollworm damaged bolls per acre in sampled fields in Cleveland County outside BWET area. North Carolina. 1977.

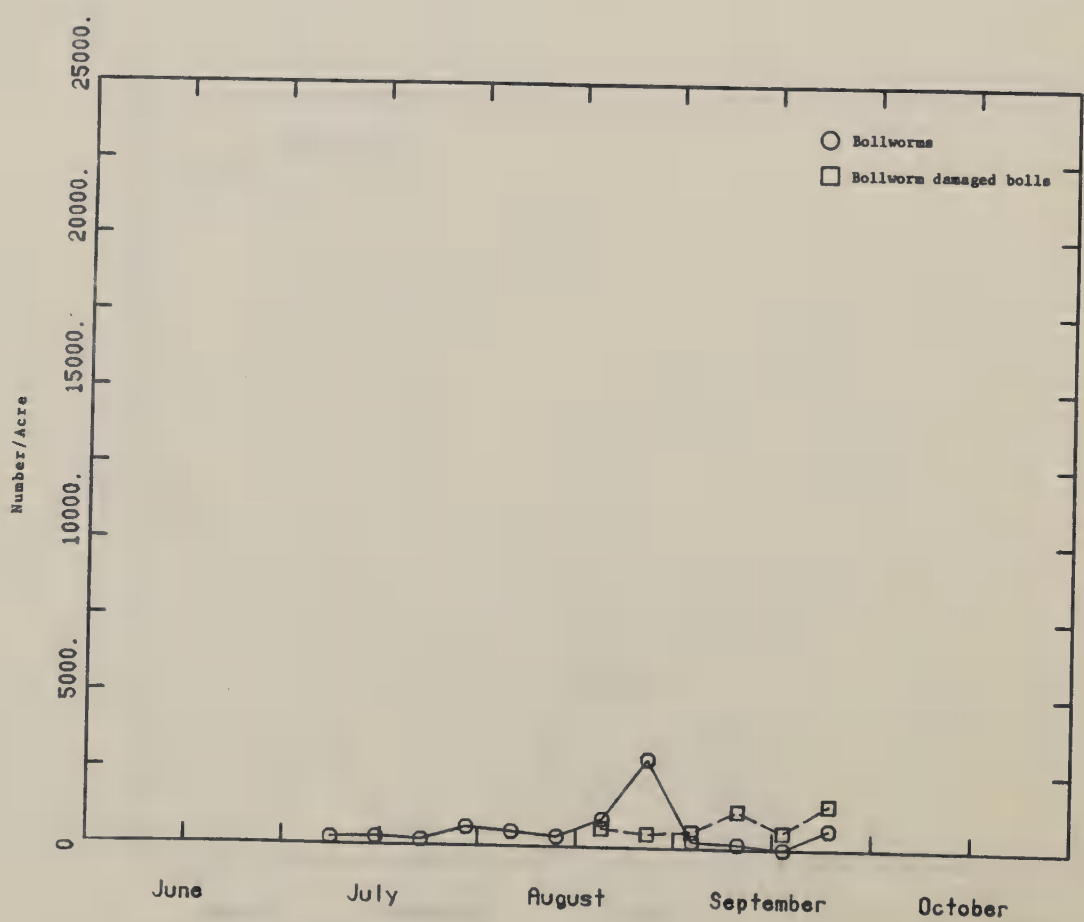


Figure 25. Estimated no. of bollworm larvae and bollworm damaged bolls per acre in intensively sampled fields in Cleveland County outside BWET area. North Carolina. 1978.

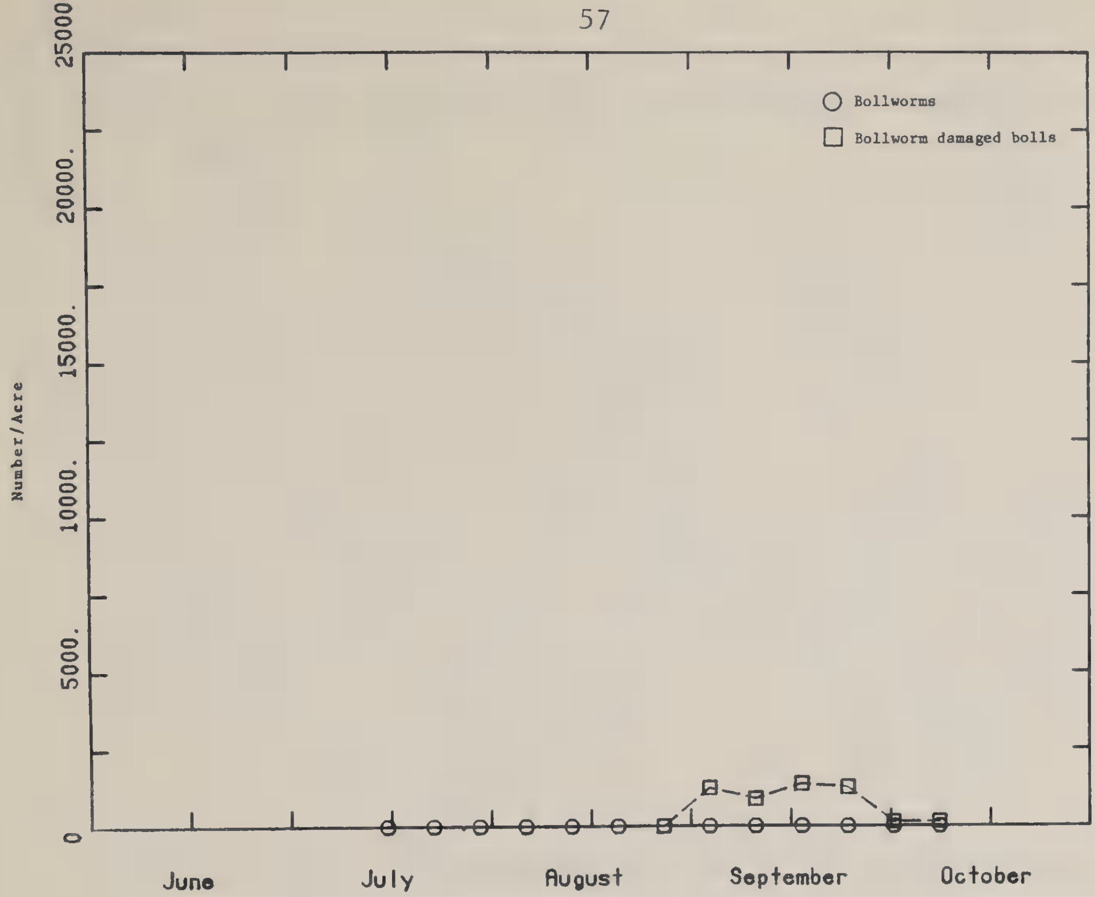


Figure 26. Estimated no. of bollworm larvae and bollworm damaged bolls per acre in intensively sampled fields in Cleveland County outside BWET area. North Carolina. 1979.

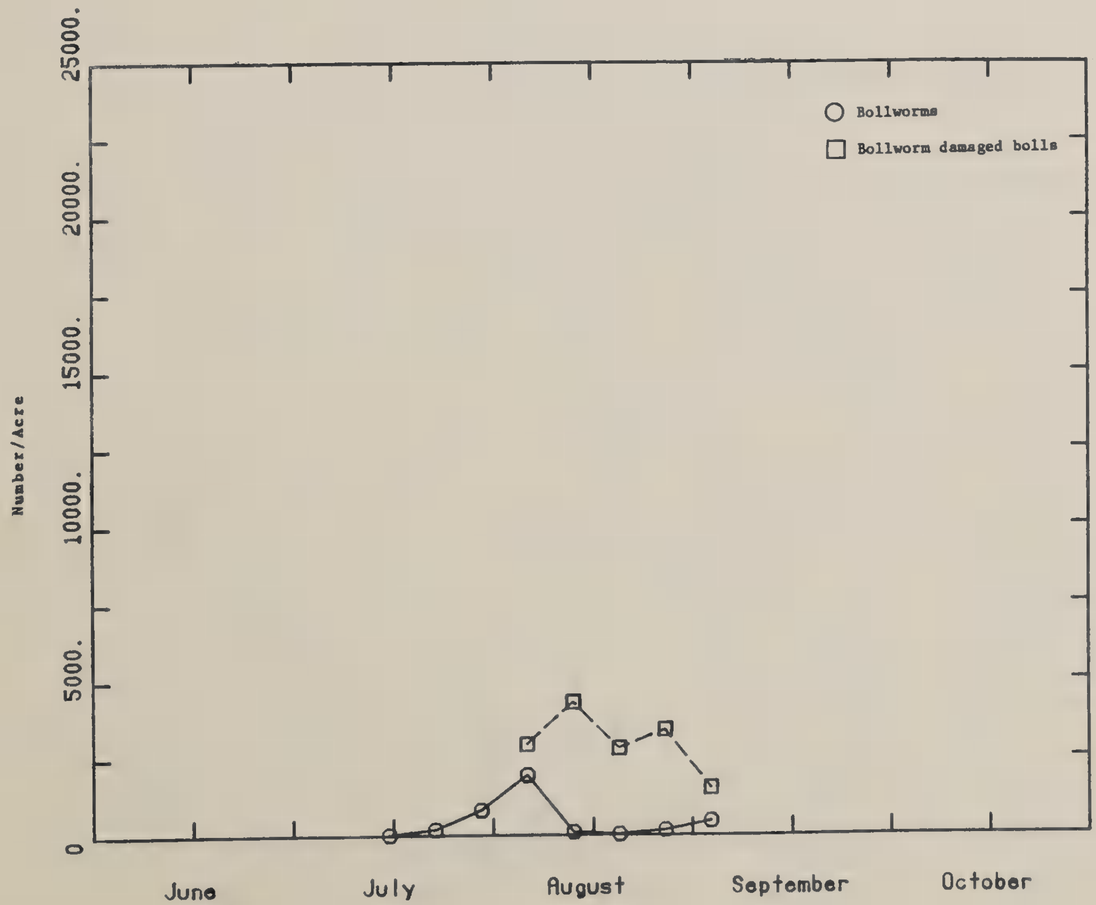


Figure 27. Estimated no. of bollworm larvae and bollworm damaged bolls per acre in intensively sampled fields in Cleveland County outside BWET area. North Carolina. 1980.

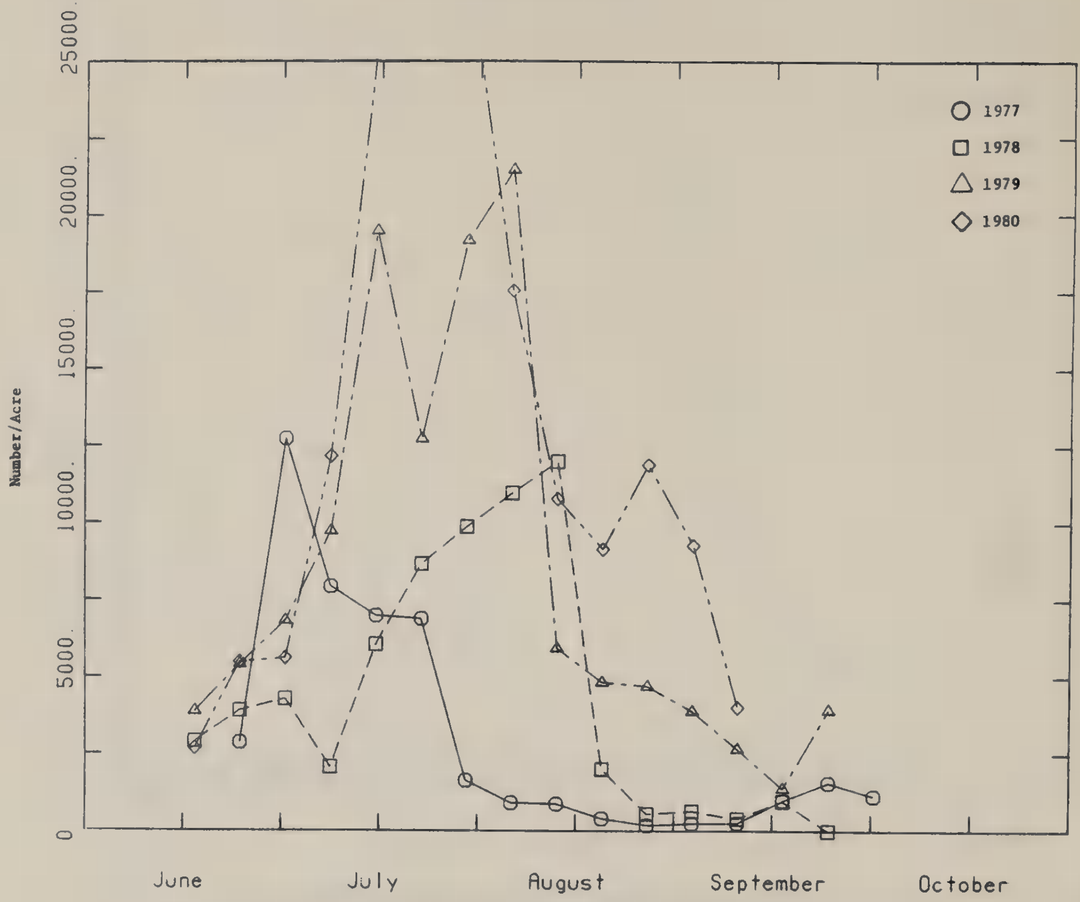


Figure 28. Estimated no. of beneficial insects per acre in 1977 sampled fields and 1978, 1979, and 1980 intensively sampled fields in the Evaluation Area, BWET. North Carolina.

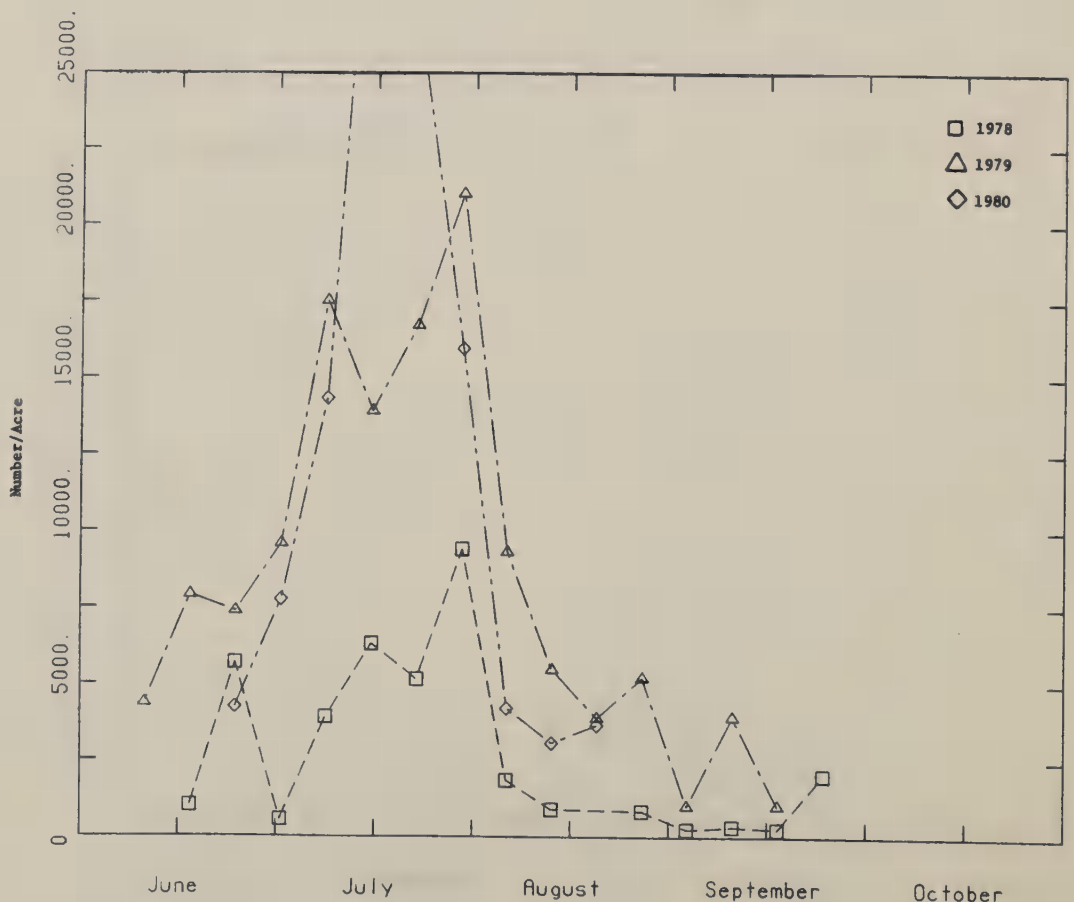


Figure 29. Estimated no. of beneficial insects per acre in 1978, 1979, and 1980 intensively sampled fields in the Buffer Area, BWET. North Carolina.

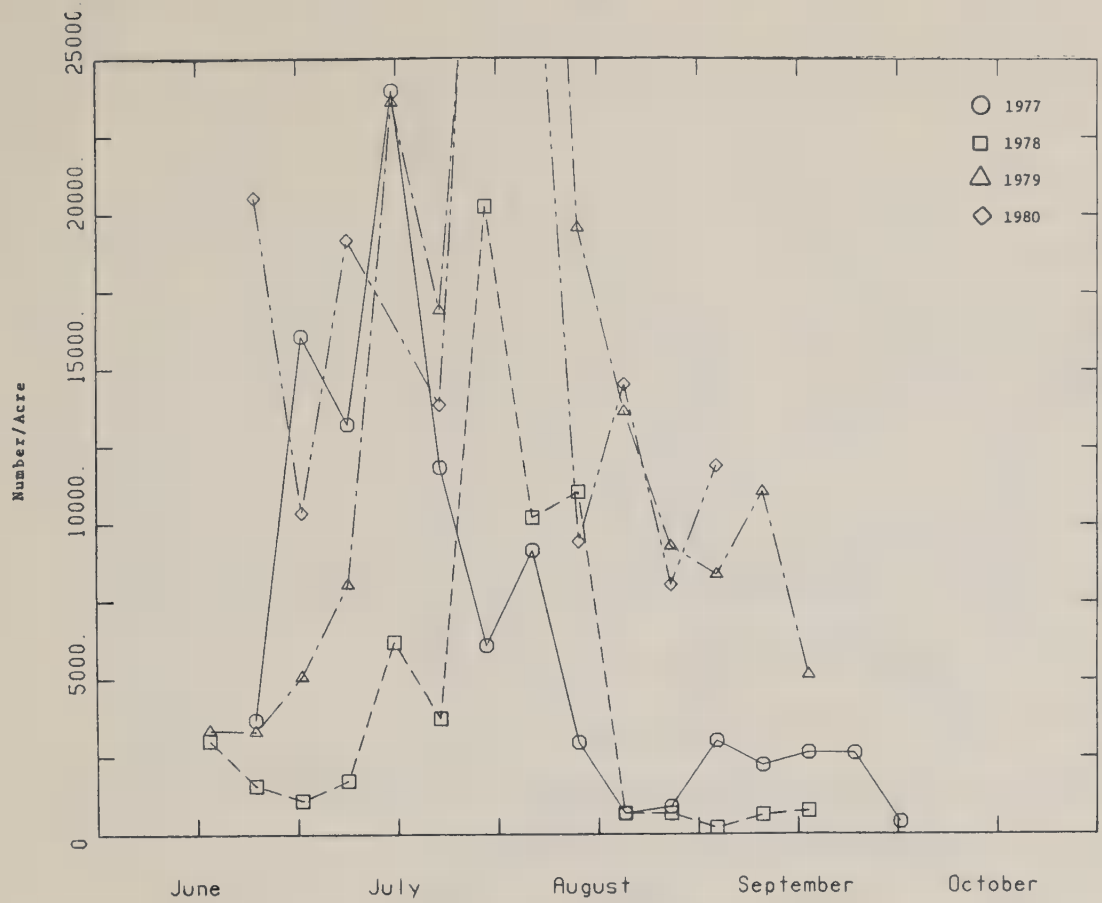


Figure 30. Estimated no. of beneficial insects per acre in 1977 sampled fields and 1978, 1979 and 1980 intensively sampled fields in Chowan County, BWET. North Carolina.

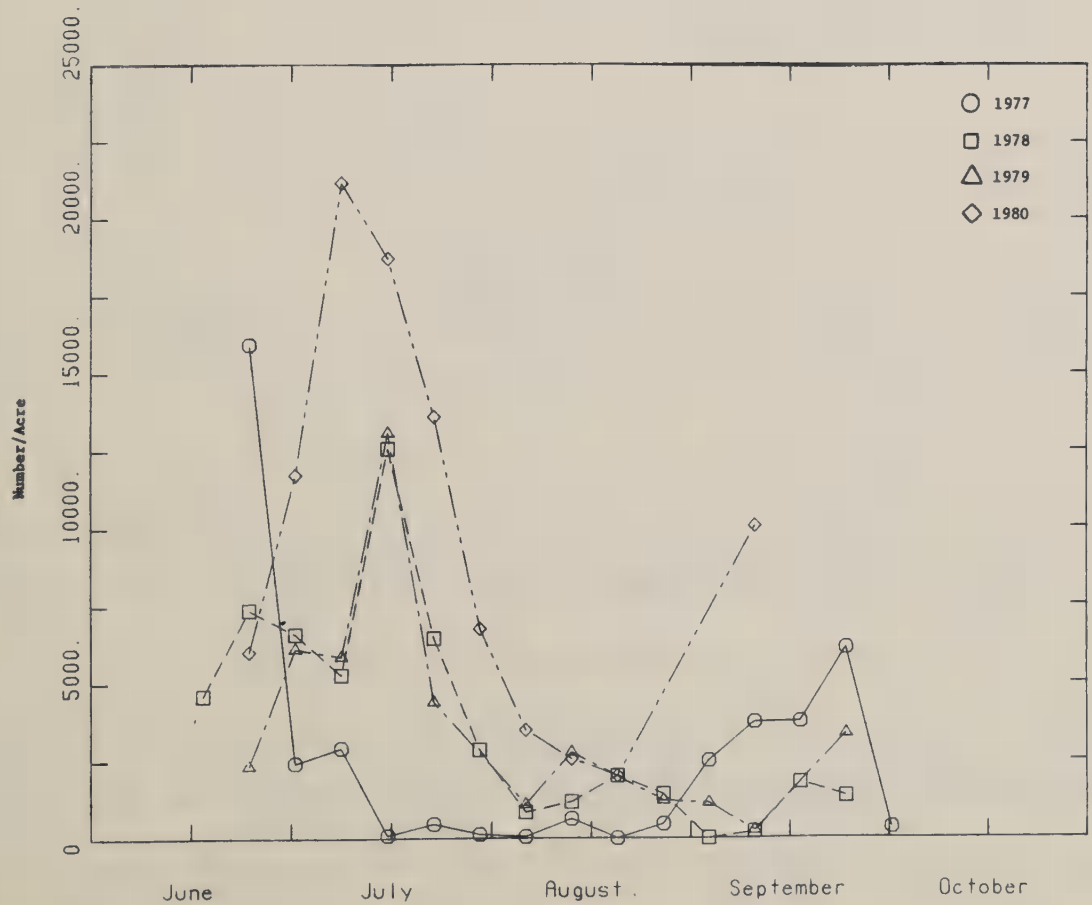


Figure 31. Estimated no. of beneficial insects per acre in 1977 sampled fields and 1978, 1979 and 1980 intensively sampled fields in Scotland-Robeson counties outside the BWET area. North Carolina.

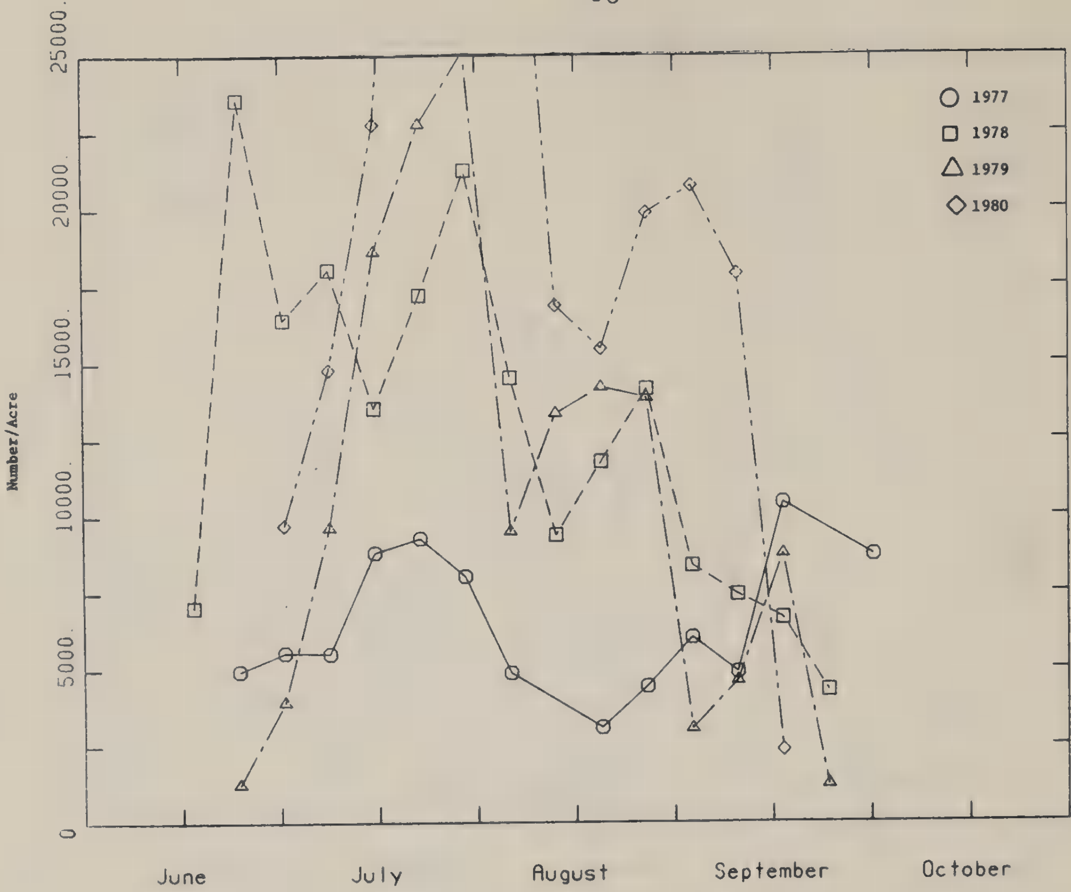


Figure 32. Estimated no. of beneficial insects per acre in 1977 sampled fields and 1978, 1979, and 1980 intensively sampled fields in Cleveland County outside the BWET area. North Carolina.

Evaluation of Biological Success

The Boll Weevil Eradication Trial, a cooperative program supported by a number of state and Federal agencies and growers, was conducted by the Animal and Plant Health Inspection Service, USDA. It was undertaken to determine if the eradication of a well established isolated boll weevil population was technically and operationally feasible. A mandatory program was instituted through a grower referendum. The Trial called for a three year program to make this determination. The goal during Year 1 (1978) was to reduce the established population to a practical minimum by instituting a well supervised inseason cotton insect control program as needed to protect the crop, followed by a thoroughly executed spray schedule to reduce the potential overwintering population. Several suppression components that were planned for Year 2 were designed to eliminate this greatly reduced population throughout the Eradication Area. The purpose of the Trial in Year 3 was to determine if eradication had been achieved and, if necessary, to eliminate any surviving infestations or reintroductions.

Plans for Year 2 called for the use of sex pheromone traps (infield type) at the rate of one trap per acre around 1978 planted cotton fields, to detect and define the location of surviving boll weevils, and to assess their relative abundance in various portions of the Eradication Area. The infield traps were also counted on to contribute to suppression. A second component of the Year 2 plan was to apply diflubenzuron (Dimilin®) to cotton fields where surviving boll weevils were suspected. The third component involved the release of sterile boll weevils in all cotton fields during a 4-week period beginning at the pinhead square stage to negate reproduction of any surviving overwintered boll weevils. All of the suppressive measures were focused on the overwintering population, which is a highly

vulnerable period for an attack on the pest.

After the releases of sterile boll weevils were terminated, infield traps were installed in all fields at an average of 2 per acre to detect the presence of F_1, F_2, or F_3 progeny that could have resulted from reproduction by surviving overwintered weevils following the sterile boll weevil releases. These infield traps could also capture possible late emerging overwintered boll weevils. Any inseason infestations detected were to be eliminated by the application of insecticides. Prior investigations (Lloyd et al. 1980; Leggett et al. 1980) have shown that 2 infield traps per acre will detect progeny of a single reproducing overwintered boll weevil by the F_2 generation. Even one trap per acre detected progeny in all of 7 experimental fields by the F_2 generation. The probability of detecting F_1 progeny with 2 traps per acre was calculated to be 94%. The use of infield and border field traps permits a determination of the presence or absence of low level boll weevil reproduction with virtually 100% certainty which serves to guide necessary actions with optimum efficiency and effectiveness.

Trapping logistics and results (Table 10) provides a measurement for evaluating biological success of the trial.

The program during Year 1 was carried out essentially as planned. It involved 5 applications of organophosphorous insecticides, including one defoliant treatment, following the regular season control program. The boll weevil population was low because of the intensive use of insecticides for control of bollworms and tobacco budworms and two successive cold winters. The boll weevil population was estimated to be 11,000 adults (based on 1977 acreage) emerging in 1978. Trapping data during the fall of 1978 indicated that a low potential overwintering boll weevil population survived the inseason program. This fall population was estimated to

Table 10.--Boll weevil trapping logistics and results for indicated periods and areas (cotton field traps only).

	No. Traps 1/			No. Boll Weevils Detected			Avg. No. Boll Weevils/ 1,000 Traps		
	Spring hiber- nation Traps	Summer Infield Traps	Fall Border Traps	Spring Hiber- nation Traps	Summer Infield Traps	Fall Border Traps	Spring Hiber- nation Traps	Summer Infield Traps	Fall Border Traps
Evaluation Area									
1977	-	-	450	-	-	1,354	-	-	3,008.89
1978	3,383	-	2,293	199	-	1,009	58.82	-	440.03
1979	14,676	30,244	19,399	7	0	2	0.48	0	0.10
1980	16,564	26,263	22,701	1	0	10 2/	0.6	0	0.44
Buffer Area									
1977	-	-	-	-	-	-	-	-	-
1978	713	-	678	67	-	37	93.97	-	54.57
1979	3,722	4,253	3,864	38	70	867	10.21	16.46	224.38
1980	4,031	5,549	5,087	117	133	11,608	29.02	23.96	2,281.89
Chowan Co.									
1977	193	193	824	22	26	170	113.9	134.7	206.3
1978	760	-	760	10	-	0	13.2	-	0
1979	420	1,458	1,293	0	0	0	0	0	0
1980	1,117	1,548	1,548	0	0	0	0	0	0
Outside Area 3/									
1978	-	-	95	-	-	136	-	-	1,442.00
1979	712	-	1,541	3,640	-	117,894	5,112.36	-	76,504.87
1980	1,559	-	1,512	78,478	-	483,260	50,338.68	-	319,616.40

1/ Spring hibernation, summer infield and fall border traps were generally operated April 15 - July 30, July 15 - August 30, and September 1 - November 1, respectively.

2/ All 10 boll weevils detected were in one localized portion of a single cotton field. An additional 4 boll weevils were captured in migration traps located away from cotton fields in the southern edge of the Evaluation Area. Total detections in the Evaluation Area in 1980 = 15 boll weevils.

3/ Outside area constitutes a survey of sample cotton fields within a 100-mile area south from the outer Buffer Area boundary. South Carolina trapping coordinated by Clemson University, Clemson, SC.

be 49,000 boll weevils (or at least 4 per acre on 1978 acreage) up to and including part of the period when 5 diapause control treatments were applied. Previous experiments have shown that 99% were prevented from entering overwintering quarters by these diapause control treatments. The colder than average winter probably killed 95% of those entering winter quarters. These degrees of suppression project 490 weevils entering hibernation in 1978 and 25 emerging in 1979 which is a reasonable estimate. In 1979, only 7 overwintered boll weevils were captured in 14,676 traps, used at the rate of 1 trap per 0.85 acre around 1978 cotton fields, which aggregated 12,485 acres. The 7 weevils project to a total overwintered population of 15 in the entire Evaluation Area based on trap sensitivity at the trap density used in the trial.

In Year 2 (1979), applications of diflubenzuron were made on 400 acres of cotton in the Evaluation Area as a security measure. Sterile boll weevil releases were also made as planned. A total of 11.2 million sterile boll weevils were released averaging 139 per acre each week for 4 weeks. Trap capture data indicated that the released boll weevils dispersed well, and some 90,000 of the ebony marked weevils were captured in field border traps while no native boll weevils were taken during the release period. Based on the assumption that the total number of overwintered survivors after releases began was well under 100 (calculated 15-25), the overall ratio of sterile to native boll weevils would have exceeded 100,000:1. The possibility of even one fertile mating in the entire Eradication Area would be remote even though the sterile boll weevils are relatively low in competitiveness, as field data indicate. Results of the infield trapping phase of the program demonstrated the absence of reproduction. No boll weevils were captured in the

infield traps which were in operation until F_3 emergence normally would occur. Taking into account the very low number of overwintered survivors and the high degree of sensitivity of infield traps and subsequent border traps for the detection of reproduction, we concluded that there was a probability of >0.9983 (see next page) that boll weevil eradication in the trial program was achieved by Year 2. In September and October 1979, 2 boll weevils were captured in border traps and were assumed to be reintroductions because of the location of their capture and because no reproduction was detected by infield traps in the Evaluation Area.

In 1980 (Year 3), all cotton grown in the Eradication Area was monitored by the use of early season traps at the rate of somewhat more than 1 per acre around cotton fields followed by the use of infield traps at the rate of 1 per acre during the growing season and followed again by the operation of border traps at the rate of almost 1 per acre during the fall. In May 1980, a headless boll weevil believed to be carried over the winter in a stored trap was found during the first trap inspection. Four additional weevils were captured between August 18 and October 28 in migration traps just inside the Evaluation Area but distant from cotton fields. Observed dispersal of boll weevils from infested cotton supports the contention that these 4 weevils were migrants from outside the Eradication Area. On September 11, a single adult boll weevil was discovered in a 10 acre cotton field just south of the North Carolina/Virginia line approximately 90 miles from the nearest known boll weevil infestation. Nine additional boll weevils (including one pupa) were subsequently found between September 15 and 24 in that field which confirmed that reproduction had occurred. These appeared

to be the progeny of a single, reintroduced female weevil as developed below. This population was not considered to be "native." This infestation was eliminated by intensive trapping and the application of cultural measures including early harvest and stalk destruction. No additional weevils were captured after September 24, 1980 until frost, with intensified trapping. (See further details in Attachment C, p. 15-16.)

> To determine the level of probability that boll weevils were absent between October 1978 and September 1980, the following analyses were done: Trapping experiments conducted in North Carolina during 1978 and 1979 with known populations of boll weevils provided the basic data on the relationship between trap density and probability of capture when traps are used inside the field during the reproductive period. The weevil populations were initiated by placing infested squares into the test plots in a manner designed to simulate the egg laying of an overwintered female weevil. The probability of a given female weevil being captured was defined in equation form as a function of trap density and the trap-to-male ratio. The capture of male weevils was ignored since an insignificant number of males are captured during the reproductive period. The trap-to-male ratio reflects both trap density and competition from male weevils. The probability of capturing at least 1 female weevil from a population of f females over a period of d days was thus expressed as: $P=1-[1-(.0318+.0381\ \ell n\ (\text{traps/acre})+.01218\ \text{traps/male ratio})]^{fd}$.
>
> In the first analysis, probabilities were calculated (below) for capturing at least 1 weevil for the indicated static population levels for indicated trapping periods following introduction assuming 1 trap/acre. It was assumed that no reproduction occurred in this analysis.

Total population (male and female)	Trapping period, days: 10	20	40	80	160
2	.36	.59	.83	.97	>.99
4	.54	.79	.95	>.99	>.99
8	.76	.94	>.99	>.99	>.99
16	.93	>.99	>.99	>.99	>.99
32	.99	>.99	>.99	>.99	>.99

> A more realistic approach is to generate populations of boll weevils using a simulation model. The Cotton Insect Management (CIM) model (See Attachment B. 17) was used to simulate a crop season in the Evaluation Area of North Carolina for the crop years

1979 and 1980. Populations of boll weevils were started by introducing 2 weevils, assumed to be 1 male and 1 female. Each simulation run was made with an introduction of 2 weevils on either June 14, June 30, July 31, or August 31. Model predictions for the total weevils present each day were used to compute the probability of capturing at least 1 weevil for the time period up until September 1, the approximate date when the infield traps were moved to the field borders. The probability of detection after the traps were removed to the field borders was ignored since capture probability data used in this analysis applies to capture of weevils with infield traps. If capture probability data were available for border traps, border trapping could be included, and would increase the overall probability of detection. Finally, the least probable situation of overwintering emergence, July 31, was chosen for both years, in that this date is about the latest date for boll weevil emergence that is probable. The simulations for weevils introduced June 14 and 30, which represent more normal emergence from overwintering, gave higher probability values.

The overall probability of detection with this late emergence for 1979 and 1980 combined was .9983. The upper and lower 95% confidence limits are >.9999 and .8612, respectively. This high probability of detection, and the fact that no boll weevil reproduction was discovered between October 1978 and the above mentioned September 11, 1980 infestation, points strongly to this infestation being a reintroduction.

The statistical anaslysis and calculation of the probability values presented above were performed with the assistance of Dr. Robert J. Monroe, Professor of Statistics at North Carolina State University, and Dr. Raymond Heiser, Associate Professor of Statistics at Mississippi State University.

It should be noted that the success of the trial program was preceded by a smaller but equally impressive demonstration of the capability of eliminating an isolated boll weevil population with technology now available. Cotton in Chowan County, N.C., a well isolated cotton growing community, where from 300-1,500 acres of cotton were produced during 1977-1978, was subjected to a pre-trial program in order to gain experience with the suppressive techniques and the operational procedures to be employed in the trial program. In the process of carrying out this preliminary program, the population was eliminated. Intensive surveillance since July 1978 has not detected any infestations in Chowan County. There have been no reintroductions into Chowan County and this area, while relatively small, demonstrates

the successful use of eradication technology a year earlier than in the Evaluation Area.

Estimates of beneficial arthropod populations have increased during the period 1978-1980 in the 3 sample areas included in the Eradication Trial. The two CIC-Practice Areas outside the Trial have also demonstrated increases in beneficial populations during the same period. In 1980, estimates of average beneficial insect populations for July and August of 1980 exceeded 17,000 per acre in the Evaluation Area and Chowan County. Corresponding 1978 estimates were approximately 6,200 per acre. These two Areas also experienced the greatest reduction in insecticide applications during the same period. Estimates of average beneficial populations in July and August of 1980 in the Buffer Area and Scotland-Robeson Counties of 14,000 and 10,000, respectively, though increasing, have remained at lower levels than the above two areas.

Average beneficial populations in Cleveland County were higher and maintained their levels for a longer portion of the growing season than the other 4 areas sampled. Because of 2 severe winters and resulting low boll weevil numbers, the inseason application of insecticide was 0 in 1978 and 1979 (in 1979, .75 treatments were applied for boll weevil diapause control). In 1980, 2 of the 4 intensively sampled fields required inseason boll weevil insecticide treatments. The two fields receiving insecticide treatments experienced significant reductions in beneficial insect levels and required 7 treatments for boll weevil and bollworm control. The average beneficial populations for the 4 intensively sampled fields was maintained at a high level by the elevated counts in the 2 untreated fields.

Estimates of beneficial arthropod populations have increased in all 5 sample areas during the 3 years of the Boll Weevil Eradication Trial.

Areas experiencing the greatest increases in beneficial populations observed a corresponding greatest decline in insecticide use. Data on estimated numbers of beneficial arthropods in the Evaluation Area and Chowan County effectively show these trends.

Insecticide applications declined in the Evaluation Area and the associated CIC area by 88% and by 25%, respectively, during the trial period compared to the 1974-1977 pre-program averages. Insecticide applications for bollworm decreased by 86% and 54% for the BWE and CIC areas, respectively, between 1977 and 1980. In 1980, 41% of the cotton fields in the Evaluation Area did not require insecticide application for bollworm control. Five insecticide applications for suppression of diapausing boll weevils in Year 1 (1978); the use of border and infield pheromone traps, diflubenzuron treatments on limited acreage and release of sterile boll weevils in Year 2 (1979); and season-long monitoring with border and infield pheromone traps in Year 3 (1980) were used successfully to eradicate ($P > 0.9983$) an established population of boll weevils from the Evaluation Area in the BWE Trial. Therefore, the BWE Trial accomplished its principal objective and was considered a technical and biological success.

Optimum Pest Mangement Trial

The Optimum Pest Management (OPM) Trial was conducted by the Mississippi Cooperative Extension Service in Panola County, Mississippi, 1978-1980 (see Attachment B. 15). Cotton in Pontotoc County, Mississippi, two counties to the east, was identified and monitored as a CIC-practice area.

Technology

Technological components of OPM, as used by the Mississippi Cooperative Extension Service, follow:

1. All cotton acreage in Panola county along with pheromone trap locations were recorded on orthophotoquad maps. Data from pheromone traps and scouting forms were mailed to the MSU Computer Center for a weekly printout of population distributions.
2. Infield and peripheral pheromone traps were used for survey and field population estimates with traps installed at about one trap per 20 acres in Panola County in 1978, 1979, and 1980. Traps were operated in Pontotoc County in 1979 and 1980 by the Research Team.
3. All acreage of participating growers was scouted at least once a week with some scouted twice by consultants or Extension Service personnel.
4. Pinhead square insecticide applications for control of overwintered boll weevil populations were scheduled if needed.
5. Inseason control was in accordance with guidelines given in the Mississippi Cotton Insect Control Guide.
6. Diapause applications were initiated in Panola County, in September, and continued on a 10- to 15-day interval for four applications in 1978, 1979, and 1980.

7. Stalk destruction was encouraged in Panola County as harvest permitted.

Evaluation Criteria

Performance criteria for OPM follow: (1) maintenance of boll weevil and other pest populations below damaging thresholds, (2) maintenance of acceptable levels of beneficial arthropod populations, and (3) acceptable levels of pesticide usage and yield.

Evaluation Methodology

AR was given the lead responsibility for developing data for the Biological Evaluation Team and for conducting research to improve existing, or to develop new, techniques which might be used as population suppression components in the Trials. This was done by a research team in both Trial Areas.

A prototype operation was conducted in 1977 in Panola and Pontotoc counties to develop base line data, to evaluate and refine techniques, and to develop procedures which would permit smooth expansion of the program when the Trial got underway in 1978. Twenty and ten cotton fields were monitored for insect, spider mite, and spider populations in Panola and Pontotoc counties, respectively, by the research team. The fields monitored in Pontotoc County represent Current Insect Control (CIC) procedures in contrast with intensive pest management practices used in the OPM Trial in Panola County.

In 1978, the number of monitored fields was increased to 64 and 32 in Panola and Pontotoc Counties, respectively. The fields were monitored weekly with 20 and 10 of those also monitored in 1977, being monitored semi-weekly in Panola and Pontotoc counties, respectively. The same procedure was used

in 1979 and 1980.

Data collection of dynamic crop information began about the last week of May when plants were in the pre-square stage of growth. Fields were monitored for boll weevils, bollworms, tobacco budworms, tarnished plant bugs, clouded plant bugs, cotton fleahoppers, thrips, cabbage loopers, fall armyworms, beet armyworms, cotton aphids, spider mites, whiteflies, and all beneficial arthropods. Populations and damage were converted to a per acre basis. Information on the numbers of plants, squares, blooms, bolls, and missing fruiting forms were collected weekly and calculated on a per acre basis. Plant height, rooting depth, and main stem nodes were recorded. All data taken were coded on special computer forms and were processed by the Mississippi State University Computer Center.

Static crop information developed for each field included acres planted, plant populations, row width, field size, cotton cultivars, peripheral ecosystem, insecticide applications, rainfall, and yield information.

In addition, trapping and field infestation data for all fields in Panola County were made available by the operations group to the Biological Evaluation Team.

Results of Research Team Studies

Data concerning boll weevil infestations were obtained for the 4-year period, 1977-1980, for Panola (OPM) and Pontotoc (CIC) counties (Figures 33 and 34 and Attachment E). After the severely cold winter of 1976-1977, boll weevil overwintered populations were very low in the prototype year of 1977, as reflected by trap captures of only 4 in May, 12 in June, and 12 in July. Population buildup was so low during the cotton fruiting period that control measures for the boll weevil, insofar as is known, were not needed in either

county. However, the numbers of weevils collected in the pheromone traps in late summer and fall--1,888 in August; 18,875 in September; 8,579 in October; and 2,388 in November--indicate considerable population buildup.

The winter of 1977-78, again, was severely cold, and boll weevil survival in 1978, the first year of the Trial, was also low. Extrapolation of trap captures based on trap efficiency indicated a population of 70,000 boll weevil adults on 32,500 acres or only about two per acre for the overwintered generation. Population buildup was slow, and only ca. 300 of the 32,500 acres in Panola County were treated for control of boll weevils. Diapause control insecticide applications in September and October were effective in reducing the boll weevil population in Panola County, as indicated by lower trap captures in the fall, than in Pontotoc County where such treatments were not made. This was further indicated in trap captures in the spring with a 75% reduction from 1978, 0.8 weevils in 1978 to 0.2 weevils per trap in 1979; and 78% below the captures in Pontotoc County in 1979.

Boll weevil populations increased sooner and in greater numbers in 1979 than in the previous two years. In Panola County, a few fields required treatment for control of the boll weevil and some for combination boll weevil/bollworm-tobacco budworm control. In Pontotoc County, all late fruiting fields were heavily infested. A few of the fields were treated and many should have been treated for control of the boll weevil. These data reflect the efficacy of the 1978 diapause control applications. Comparative captures in October 1979 in the two counties averaged 5 per trap in Panola County and 32 per trap in Pontotoc County reflecting the efficacy of the diapause control treatments in the fall of 1979.

The weather in the winter of 1979-1980 was milder than in previous years and favored boll weevil survival. In the spring of 1980, 93% fewer

boll weevils were captured per trap in Panola County than in Pontotoc County. Because of a dry period, two peaks of boll weevil emergence occurred from hibernation sites. However, a pinhead square application of insecticide was made in Panola County on only 60 of approximately 40,000 acres of cotton. Boll weevil infestations throughout the season were much heavier in fields in Pontotoc County than in Panola County throughout the season. As of August 18, 19 of 64 fields were infested in Panola County with the infestation ranging from 1 to 15% punctured squares. In Pontotoc County, 32 of 32 fields were infested with a range of 2 - 95% punctured squares. The boll weevil was a problem, especially in Pontotoc County, despite the drought which was not favorable for population build-up.

In 1977, 1978, and 1980, tarnished plant bug populations were about the same in the two counties (figures 35 and 36). They were higher and persisted longer in 1979. In Panola County, the OPM Trial had no influence on these infestations since a pinhead square application was made on only 60 acres in 1980 for overwintered boll weevil control. Such application could have reduced tarnished plant bug populations. In Pontotoc County (CIC), the tarnished plant bug population was severe and persisted longer in 1979 than in 1978 and 1977 and was somewhat higher than in Panola County. In 1980, populations in the counties were similar to those in 1977 and 1978. Clouded plant bug populations occurred in appreciable numbers for the first time in both counties in 1978 and increased in numbers in 1979. In 1980, they were similar to those that occurred in 1978 (Figures 37 and 38).

Bollworm/tobacco budworm square and boll damage was similar in the two counties, being greater in 1977, 1978, and 1980 than in 1979, and somewhat higher in Panola County than in Pontotoc County (Figures 39-42). Apparently, OPM program components applied in 1978 and 1979 in Panola County did not

result in increased populations since they were similar in 1979 and 1980. Fruiting patterns (squares, blooms, and bolls) in Panola and Pontotoc counties for 1978-1980 may be noted in Figures 43-48.

Beneficial insect populations were similar in the two counties in the four years. Populations were high in 1977 and moderate in 1978, 1979, and 1980 (Figures 49 and 50). In all four years, they had considerable impact on bollworm-complex populations and especially so in 1978, 1979, and 1980 when extension personnel, consultants, and growers became aware of their importance resulting from the work of the OPM Research Team in 1977 and thereafter. Since beneficial insect populations were similar in 1979 and 1980 to those in 1978, the boll weevil diapause control treatments applied in the fall of 1978 and 1979 apparently had no adverse effect on such populations.

Data on insecticide usage were developed for each monitored field in the two counties in 1977, 1978, 1979, and 1980 and extrapolated for the total acreage in each county. Data on acreage and insecticide use may be noted in Tables 11 and 12, respectively.

Usage of both biological materials, *Bacillus thuringiensis* (*B.t.*) and *Baculovirus heliothis* was light in Panola County in 1977, none was used in 1978 and 1980, and only a small amount of *B.t.* was used in 1979. Neither was used in Pontotoc County until 1980, when a small amount of the *B. heliothis* was used.

Small amounts of acephate were used in Panola County in 1977 and 1979, and only very small amounts of azinphosmethyl were used in 1977 and 1980. Very small amounts of both materials were used in Pontotoc County in 1978 with some azinphosmethyl used in 1980.

A small amount of chlordimeform was used in Pontotoc County in 1978 and 1980, and a moderate amount was used in Panola County in 1979 and 1980,

mostly in mixture with other compounds.

Small amounts of chlorpyrifos were used in all three years in Pontotoc County with a moderate amount used in Panola County in 1977 and a small amount in 1979. Similar amounts of dicrotophos and dimethoate were used in 1977, 1978, and 1980, in Panola County with increased amounts used in 1979 reflecting need for controlling tarnished plant bug populations. Lesser amounts of dicrotophos were used in 1977, 1978, and 1979 in Pontotoc County.

A small amount of Endrin was used in Panola County in 1979 and in 1980.

Use of EPN in the EPN + methyl parathion mixture was high in Panola County in 1977 and decreased by about 70 percent in 1978 and by about 60 percent in 1979 and 1980. Comparatively small amounts of EPN were used in 1977, 1978, and 1980 in Pontotoc County.

Fenvalerate was used in 1978 in Panola County with increased usage in both 1979 and 1980. A small amount was used in Pontotoc County in 1977.

Methomyl was used in moderate amounts in Panola County in 1977 with a decrease in usage indicated in 1978 and 1979 and a further decrease in 1980. Small amounts were used in Pontotoc County in 1977 and 1979 with an increase in usage in 1980.

Methyl parathion in mixtures with EPN and toxaphene was used in considerable amounts in Panola County in 1977. Usage decreased in 1978 reflecting advent of the pyrethroid insecticides and lower *Heliothis* spp. infestations. Some increase in usage occurred in 1979 and 1980 over 1978 because of lighter *Heliothis* spp. infestations, and growers were inclined to use more economical insecticides. Methyl parathion was used in small quantities in all 3 years with a slight increase in 1980 in Pontotoc County.

Monocrotophos was used in small amounts in Panola County in 1977 and even in lesser amounts in 1978 and 1979. Small amounts were used in Pontotoc

Table 11.--Insecticide use and cotton yield in Mississippi OPM Trial and CIC areas in 1977-1980.

Year	County	Acres	Thrips[1/]	Average number applications: Lygus bugs	Bollworm/ tobacco budworm[2/]	Boll weevil	Yield bales/A
1977	Panola	33,000	1.5	0.25	3.9		1.6
1977	Pontotoc	4,500	0.3	0	1.6		1.4
1978	Panola	32,500	0.4	0.3	1.9		1.3
1978	Pontotoc	2,800	0.06	0	0.9		1.1
1979	Panola	32,000	0.6	0.6	1.6		1.2
1979	Pontotoc	3,200	0.1	0.0	0.6		1.1
1980	Panola	40,000	0.3	0.3	2.4	0.1	1.2
1980	Pontotoc	8,000	0.1	0	1.0	1.2	0.9

1/ Insecticides used for control of thrips:

Systemic insecticides - Aldicarb, disulfoton, monocrotophos. Foliar insecticides - monocrotophos, dimethoate, dicrotophos, toxaphene.

2/ Insecticide used for bollworm/tobacco budworm-boll weevil control:

1977: EPN + methyl parathion, EPN + methyl parathion + *Bacillus thuringiensis*, EPN + methyl parathion + methomyl, EPN + methyl parathion + chlorpyrifos, methomyl, methyl parathion, methyl parathion + methomyl monocrotophos, monocrotophos + methomyl + *B.t.*, methomyl + *Baculovirus heliothis*, fenvalerate (Pydrin), toxaphene + methyl parathion.

1978: Permethrin (Ambush, Pounce), fenvalerate, sulprofos, methomyl, EPN + methyl parathion, acephate, chlorpyrifos, methomyl and azinphosmethyl.

1979: Fenvalerate, fenvalerate + chlordimeform, methomyl, paramethrin fenvalerate + methyl parathion, EPN + methyl parathion, EPN + methyl parathion + methomyl, EPN + methyl parathion + chlordimeform, toxaphene + methyl parathion, acephate, monocrotophos.

1980: EPN + methyl parathion, EPN + methyl parathion + chlordimeform, EPN + methyl parathion + chlorpyrifos, EPN + methyl parathion + permethrin, EPN + methyl parathion + pounce + methomyl, fenvalerate, fenvalerate + chlordimeform, fenvalerate + methyl parathion, methyl parathion + fenvalerate + chlordimeform, fenvalerate + azinphosmethyl, fenvalerate + methomyl, permethrin + azinphosmethyl, permethrin + methomyl + azinphosmethyl, permethrin + methomyl, permethrin + chlordimeform, permethrin + methyl parathion, methyl parathion + chlordimeform, toxaphene + methyl parathion + methomyl, and *Baculovirus heliothis* + chlordimeform + methomyl.

Table 12 Pounds of various insecticides used in monitored fields[1/] and total pounds used in Mississippi OPM Trial and CIC areas, 1977-80.[2/]

Insecticide	Year							
	1977		1978		1979		1980	
	Monitored fields (lbs)	County (lbs)	Monitored fields (lbs)	County (lbs)	Monitored fields (lbs)	County (lbs)	Monitored fields (lbs)	County (lbs)
	Panola County							
Acephate	180	4145	-	-	58	1435	-	-
Azinphosmethyl	6	150	-	-	-	-	27	471
Bacillus thuringiensis (Dipel)	200	461	-	-	50	1233	8	141
Baculovirus heliothis (Elcar)	18	403	-	-	-	-	-	-
Chlordimeform	-	-	-	-	62	1529	80.3	1427
Chlorpyrifos	199	4583	-	-	8	202	-	-
Dicrotophos	187	429	167	2970	456	11254	218	3869
Dimethoate	200	4606	43	773	456	11247	24	427
Endrin	-	-	-	-	15	380	5.7	101
EPN	1286	29626	510	9078	498	12270	677	12046
Fenvalerate	-	-	61	1089	151	3718	347	6147
Methomyl	612	14087	403	7174	433	10682	7.9	141
Methyl parathion	2235	51469	513	9139	1066	26280	896	15938
Monocrotophos	120	2763	3	54	13	316	55	984
Permethrin	-	-	234	4164	36	890	105	1867
Toxaphene	-	-	100	1791	672	16567	-	-

(continued)

Table 12 Pounds of various insecticides used in monitored fields[1/] and total pounds used in Mississippi OPM Trial and CIC areas, 1977-80.[2/]

	Year							
	1977		1978		1979		1980	
Insecticide	Monitored fields (lbs)	County (lbs)	Monitored fields (lbs)	County (lbs)	Monitored fields (lbs)	County (lbs)	Monitored fields (lbs)	County (lbs)
Sulprofos	-	-	136	2412	-	-	41	734
				Pontotoc County				
Acephate	-	-	2	7	-	-	3	34
Azinphosmethyl	-	-	48	229	-	-	37	385
Baculovirus heliothis (Elcar)	-	-	-	-	-	-	2	22
Chlordimeform	-	-	20	93	-	-	9	96
Chlorpyrifos	4	10	8	40	41	434	-	-
Dicrotophos	8	201	63	299	2	25	-	-
EPN	73	1958	34	160	-	-	73	770
Fenvalerate	9	241	-	-	-	-	-	-
Methomyl	21	557	-	-	21	218	80	841
Methyl parathion	124	3319	11	51	215	2281	447	4702
Monocrotophos	-	-	59	281	3	34	-	-
Permethrin	-	-	13	61	4	40	37	389
Toxaphene	30	804	5	24	216	2289	82	862
Sulprofos	-	-	-	-	-	-	-	-

1/ 64 and 32 fields in Panola and Pontotoc Counties, respectively.

2/ Does not include methyl parathion used in diapause control program.

County in 1978 and 1979.

Permethrin was used in moderate amounts in Panola County in 1978 with a decrease in usage in 1979 and an increase in 1980. Permethrin was used in small amounts in Pontotoc County in 1978, 1979, and 1980. Considerable increase in usage of toxaphene in 1979 over 1978 occurred in Panola County. Small amounts were used in Pontotoc County in 1977, 1978, 1979, and 1980.

A small amount of sulprofos was used in 1978 in Panola County.

In summary, an overuse of insecticides probably occurred in Panola County in 1977. Better management of insect populations in 1978 and 1979 had considerable influence in reducing the use of insecticides in 1978 and 1979. A noticeable shift to the EPN or toxaphene plus methyl malathion mixtures occurred in 1979. In 1980, the addition of ovicides such as chlordimeform and methomyl to other insecticides or mixtures of insecticides was apparent. Azinphosmethyl was added to pyrethoids in many instances for boll weevil control.

Estimated yields based on Biological Evaluation sample fields were as follows:

	Panola County		Pontotoc County	
Year	No. Fields	Avg. lb. lint	No. Fields	Avg. lb. lint
1977	20	776	10	615
1978	54	625	27	538
1979	58	559	32	574
1980	64	586	33	430

Yields were at acceptable levels with delays in fruiting by plant bugs in 1979 being offset by favorable fall weather. Boll weevils reduced yield in Pontotoc County in 1979 and especially so in 1980.

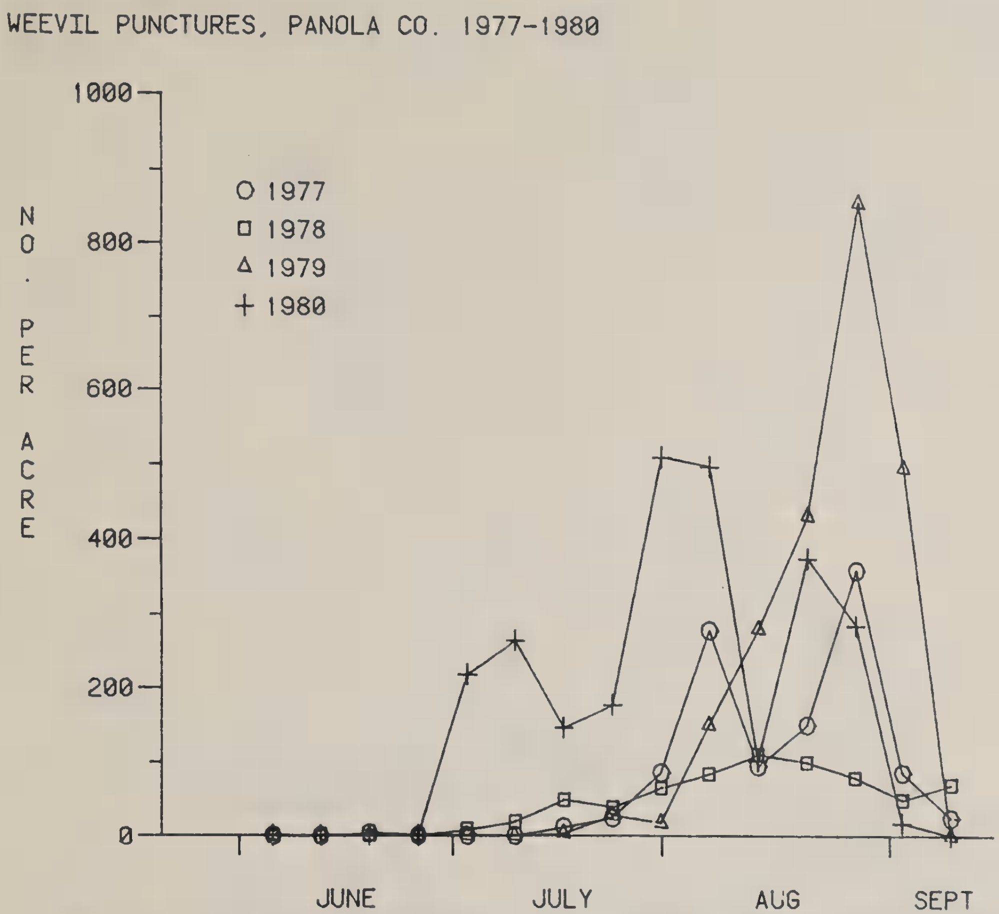


Fig. 33. Comparative, seasonal, per acre boll weevil punctured squares in Panola County, MS. 1977, 1978, 1979, & 1980.

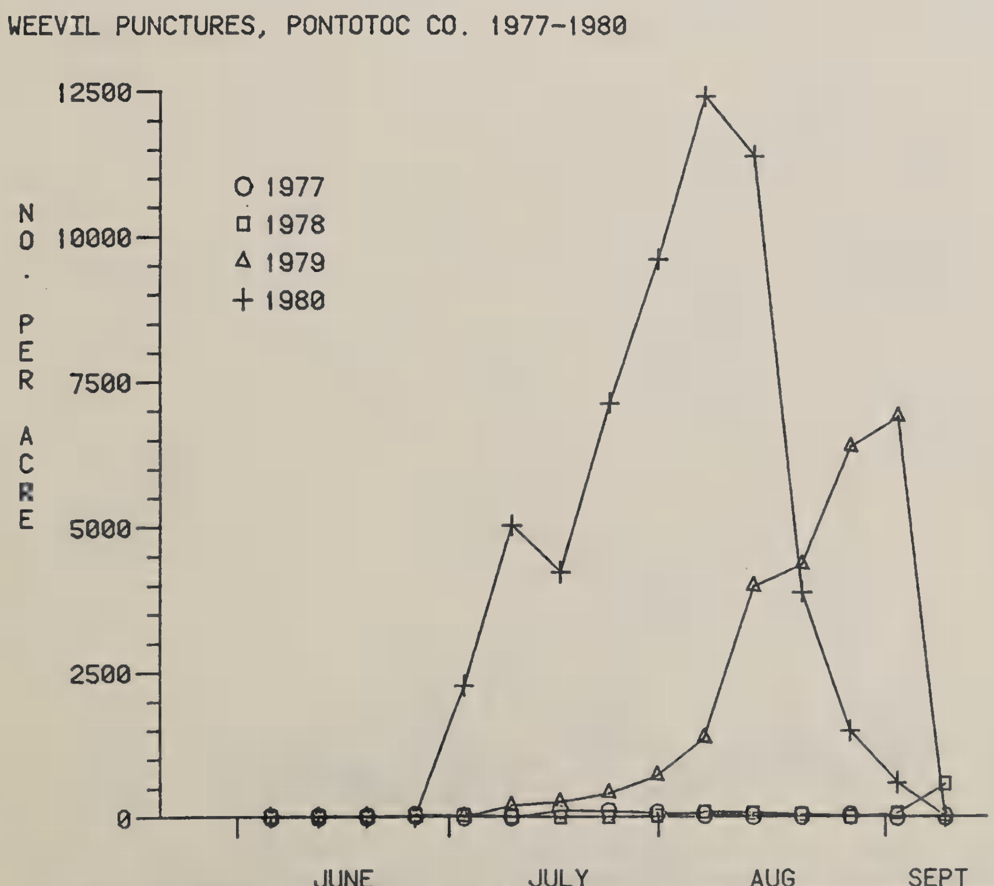


Fig. 34. Comparative, seasonal, per acre boll weevil punctured squares in Pontotoc County, MS. - 1977, 1978, 1979 & 1980.

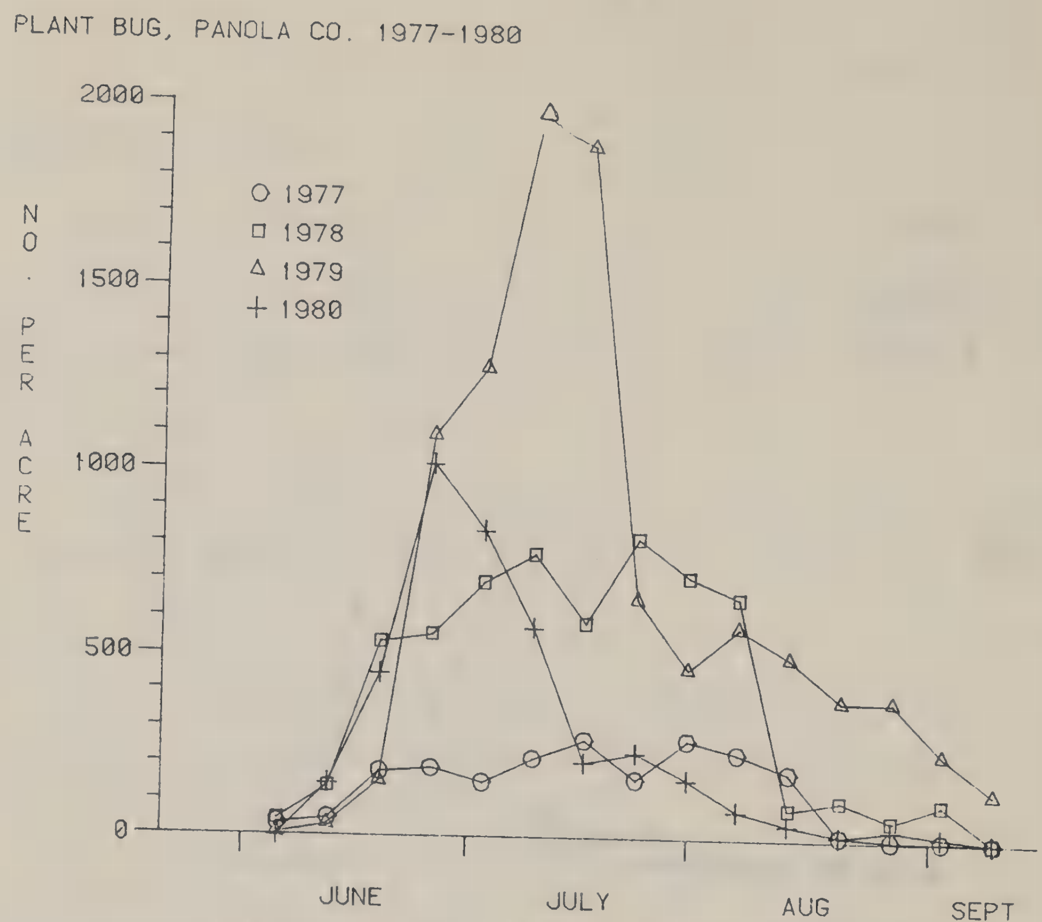


Fig. 35. Comparative, seasonal, per acre tarnished plant bug populations based on D-Vac® samples in Panola County, MS. - 1977, 1978, 1979, & 1980.

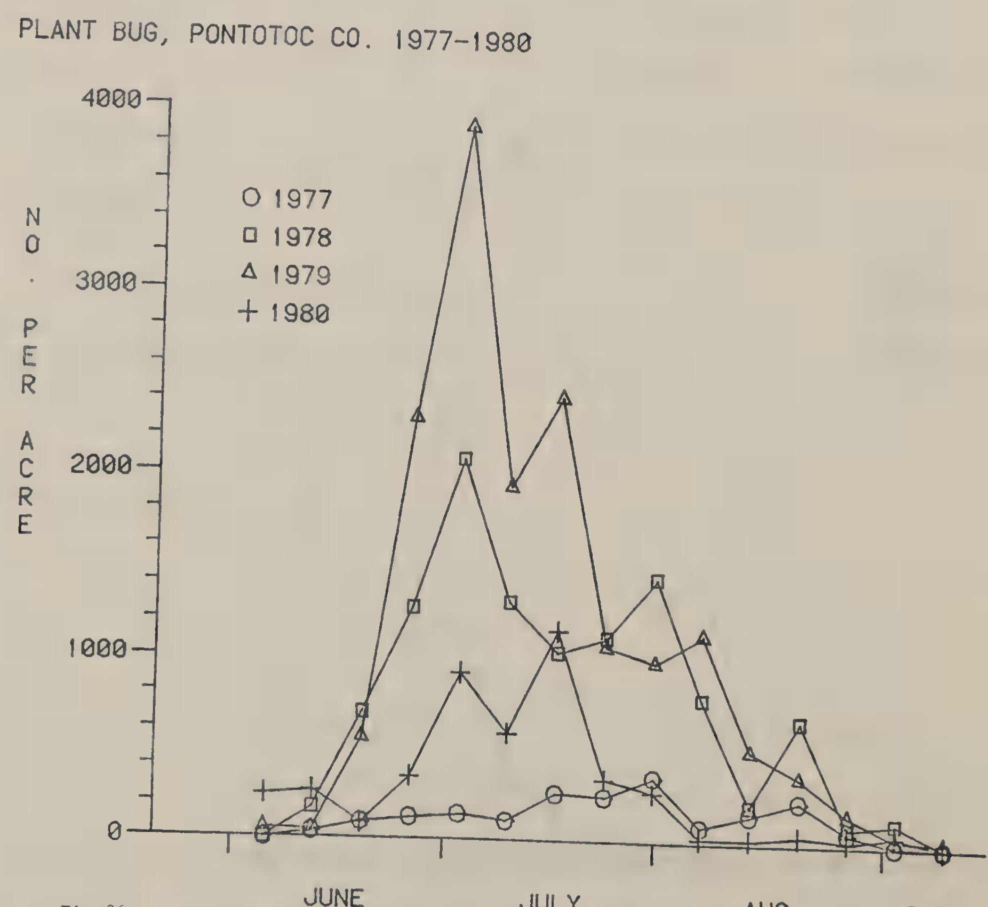


Fig. 36. Comparative, seasonal, per acre tarnished plant bug populations based on D-Vac® samples in Pontotoc County, MS. - 1977, 1978, 1979 & 1980.

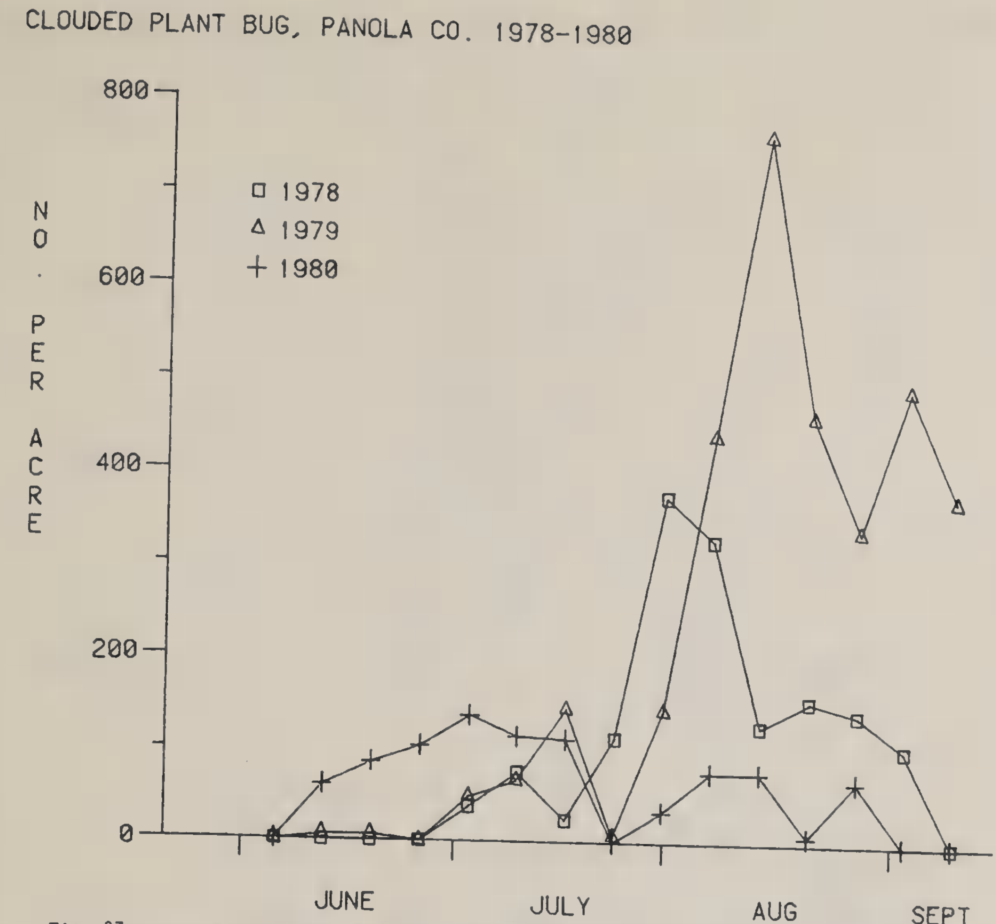


Fig. 37. Comparative, seasonal, per acre clouded plant bug populations based on D-Vac® samples in Panola County, Ms. - 1978, 1979 & 1980.

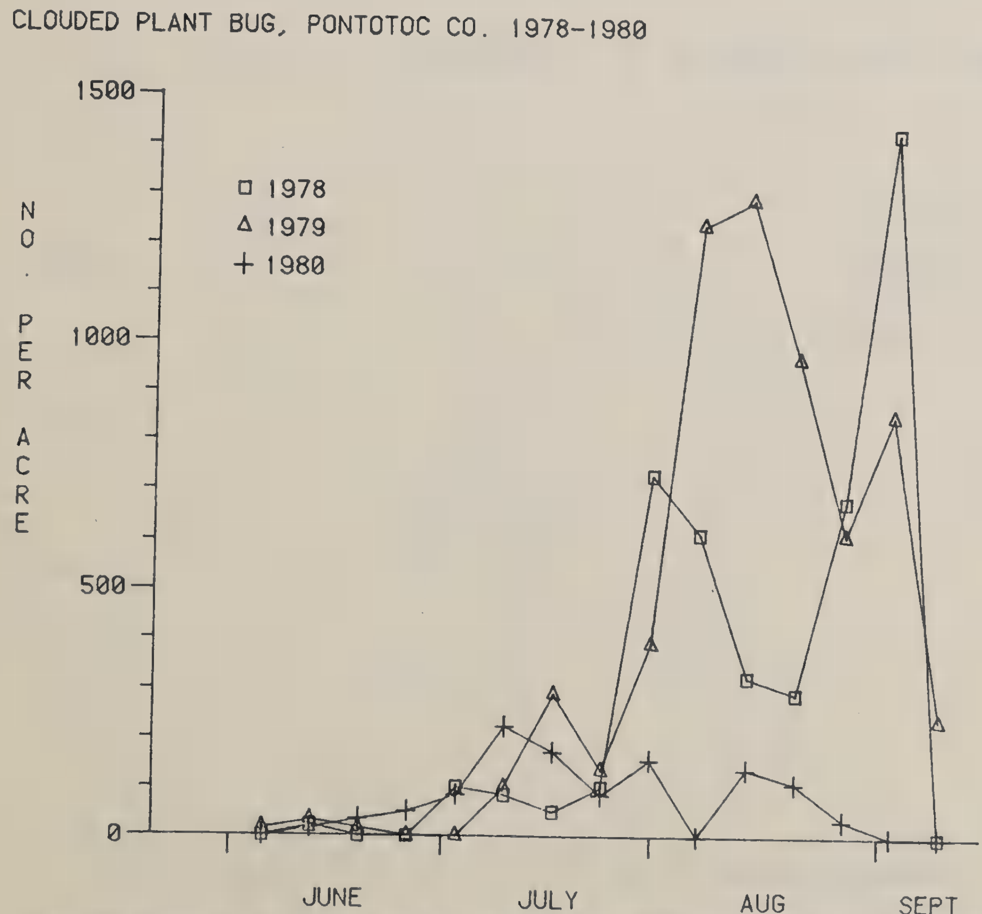


Fig. 38. Comparative, seasonal, per acre clouded plant bug populations based on D-Vac® samples in Pontotoc County, MS. - 1978, 1979, &1980.

BOLLWORM DAMAGED SQUARES, PANOLA CO. 1977-1980

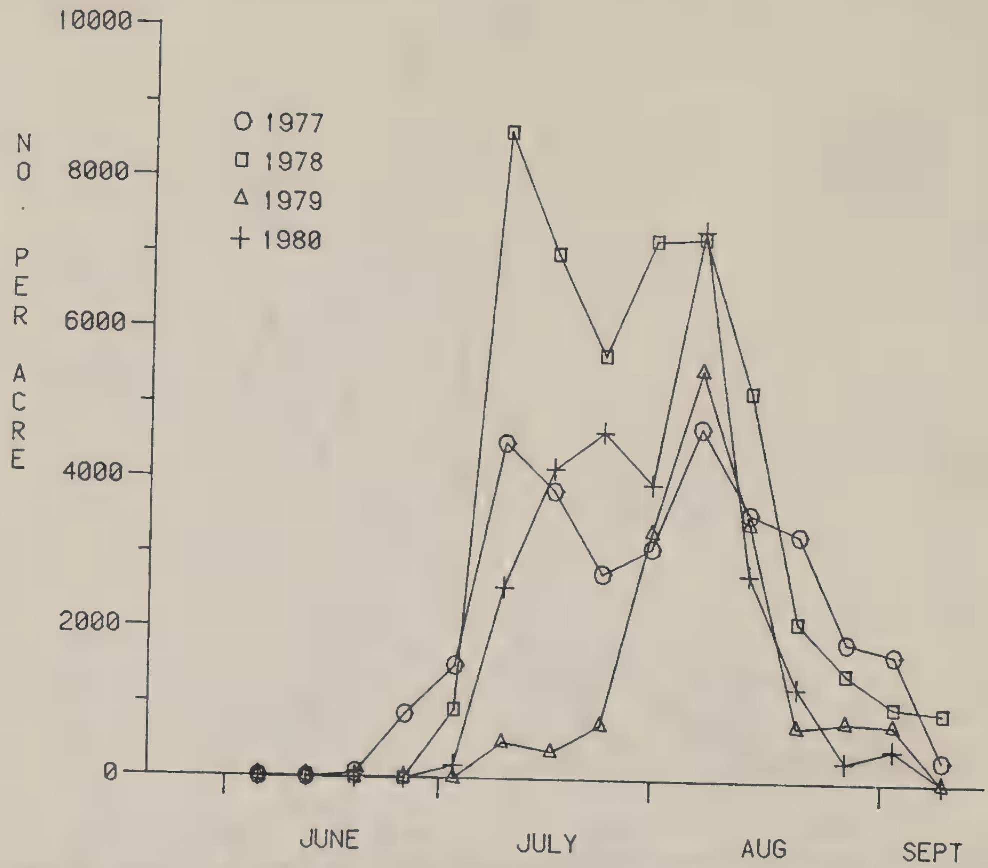


Fig. 39. Comparative, seasonal, per acre <u>Heliothis</u> spp. damaged squares in Panola County, MS. - 1977, 1978, 1979 & 1980.

BOLLWORM DAMAGED SQUARES, PONTOTOC CO. 1977-1980

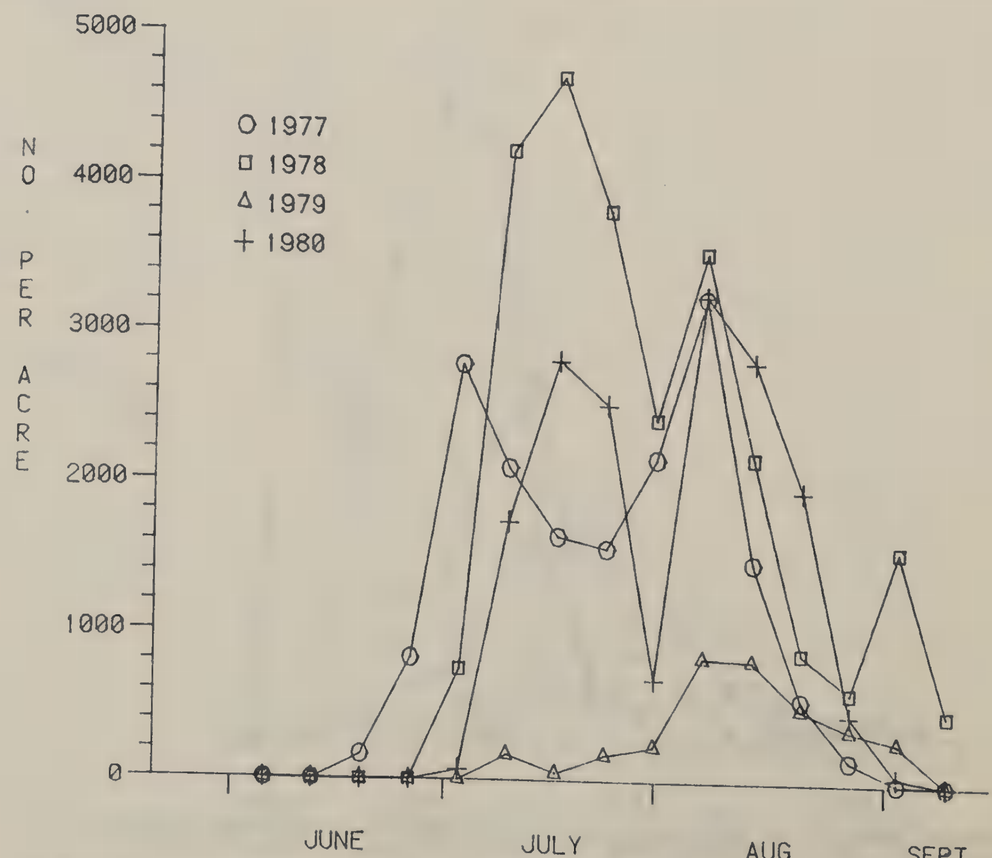


Fig. 40. Comparative, seasonal, per acre <u>Heliothis</u> spp. damaged squares in Pontotoc County, MS.- 1977, 1978, 1979 & 1980.

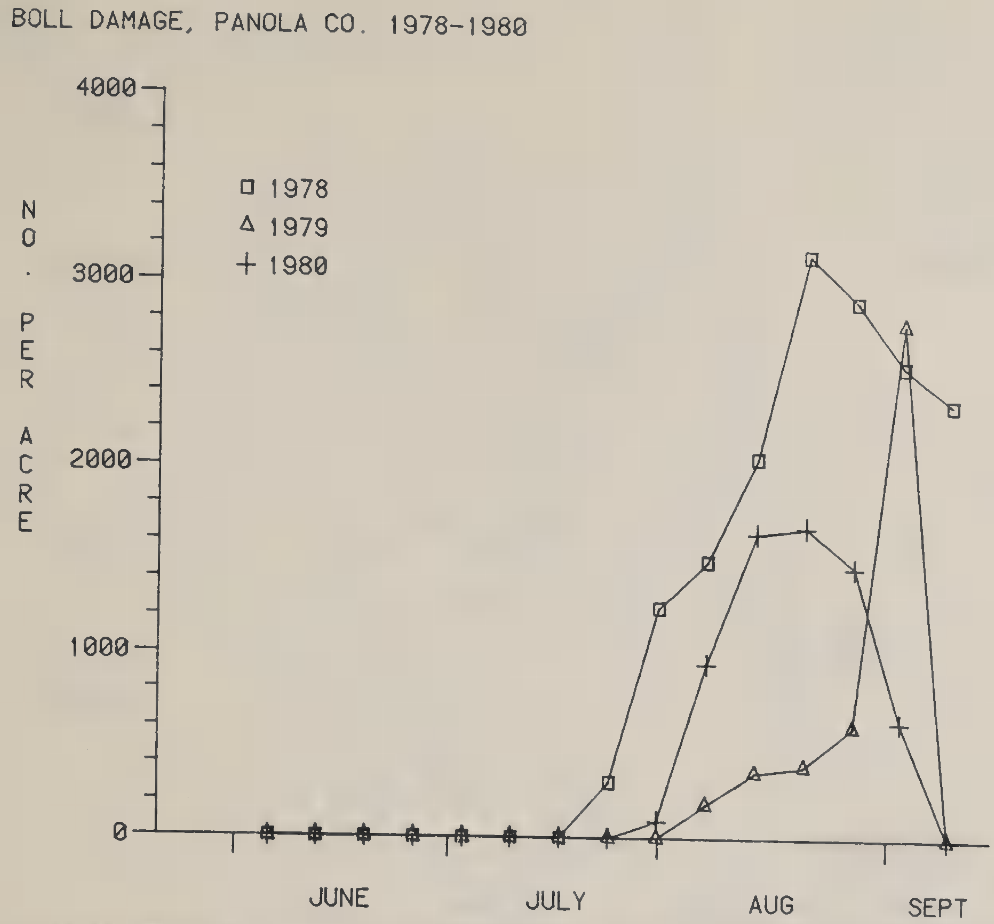


Fig. 41. Comparative, seasonal, per acre Heliothis spp. damaged bolls in Panola County, MS. - 1978, 1979, & 1980.

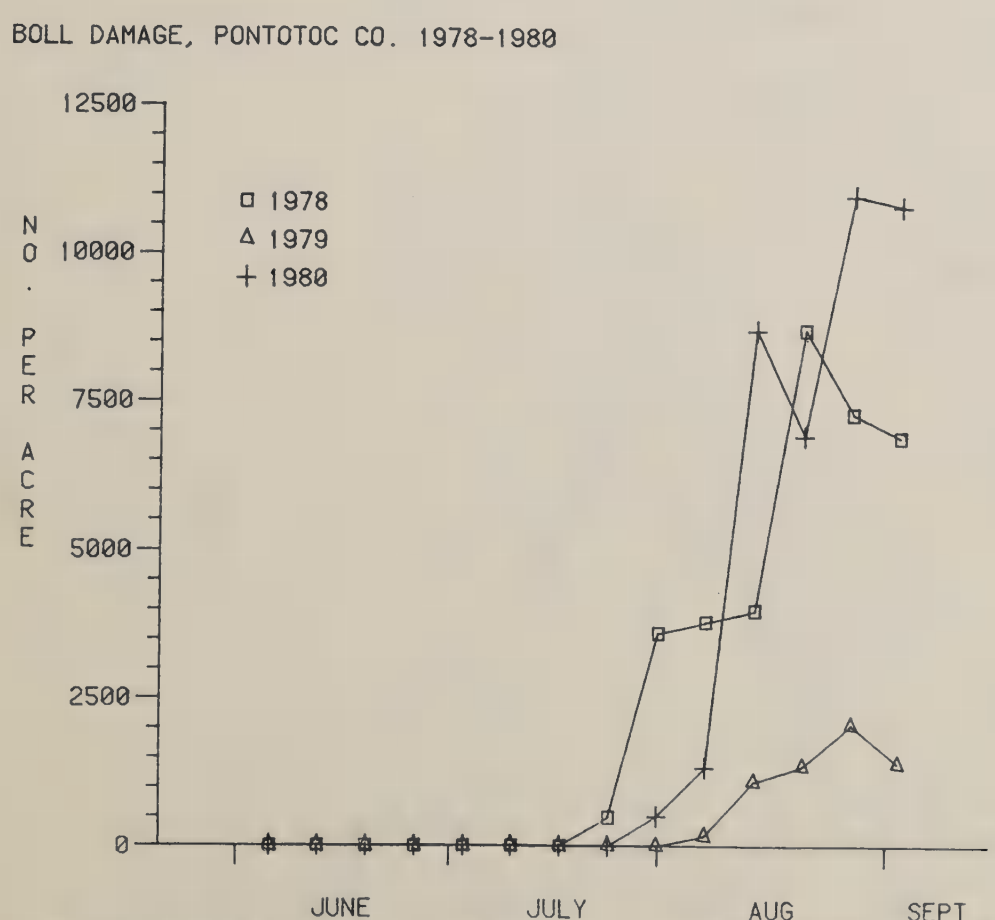


Fig. 42. Comparative, seasonal, per acre Heliothis spp. damaged bolls in Pontotoc County, MS. - 1978, 1979, & 1980.

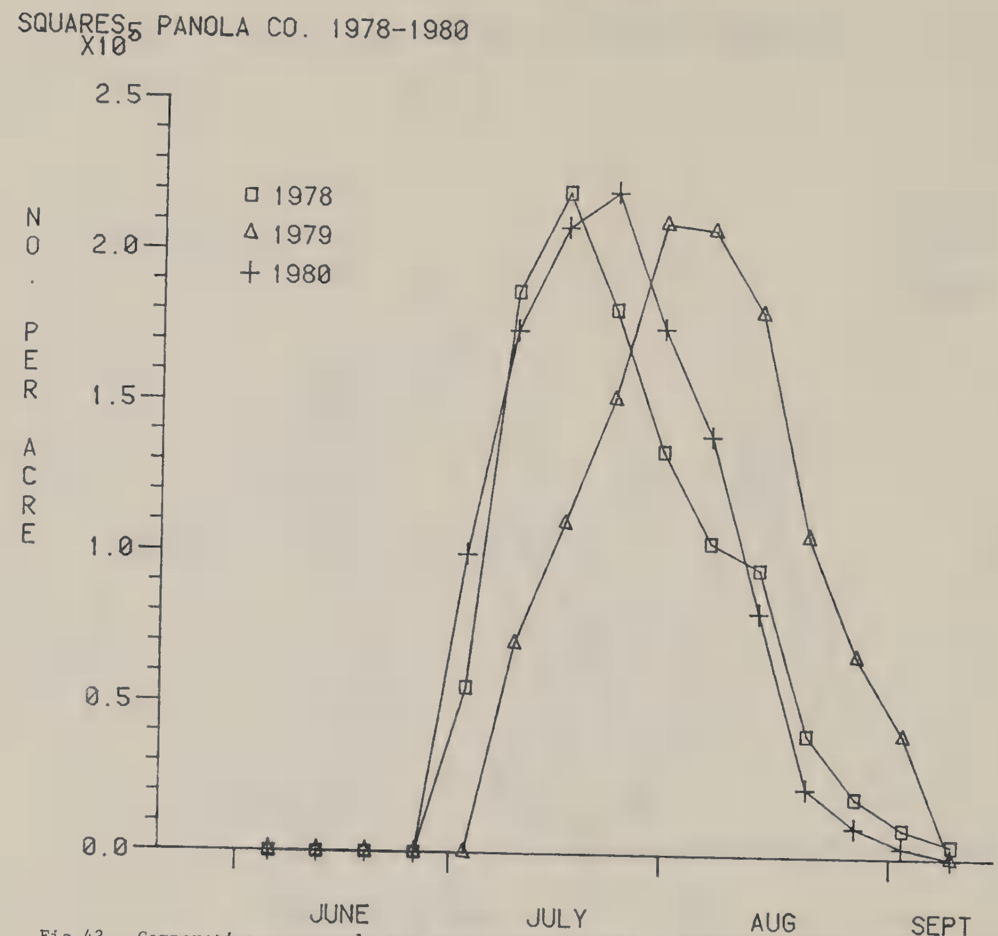


Fig.43. Comparative, seasonal, per acre average number of squares in Panola, MS. - 1977, 1978, 1979 & 1980.

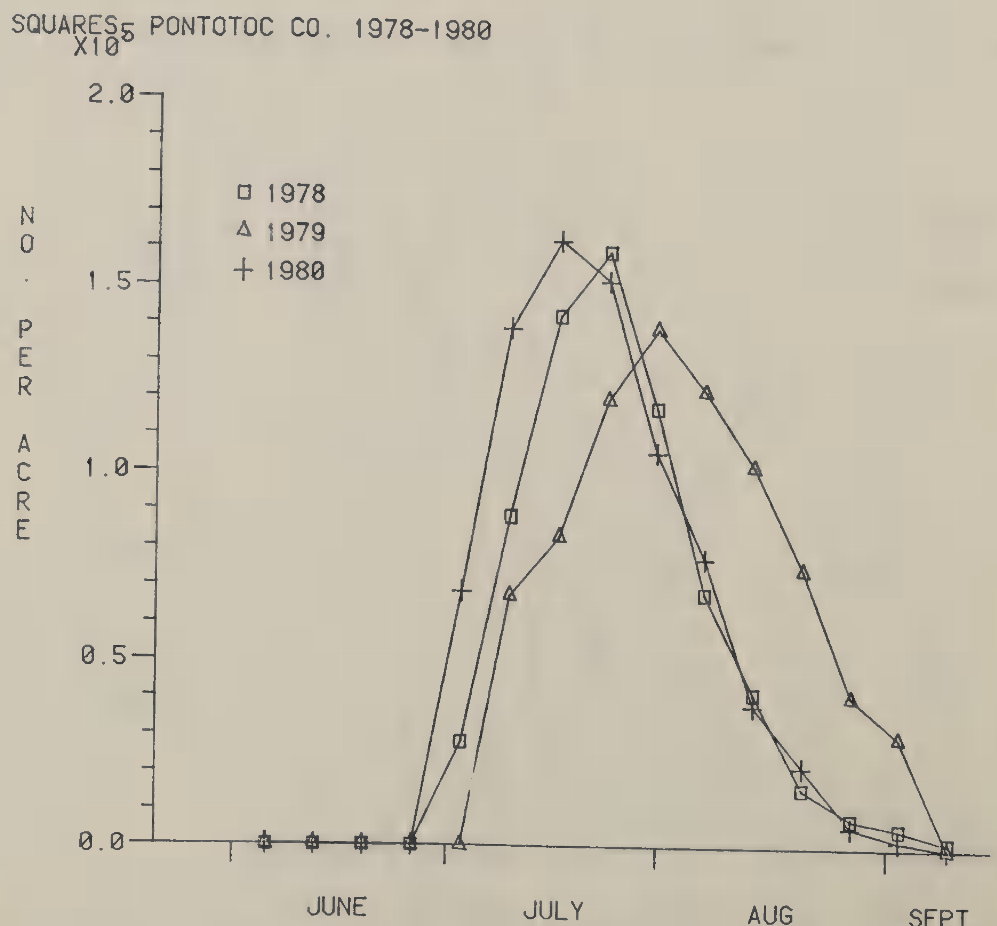


Fig. 44. Comparative, seasonal, per acre average number of squares in Pontotoc County, MS. - 1977, 1978, 1979 & 1980.

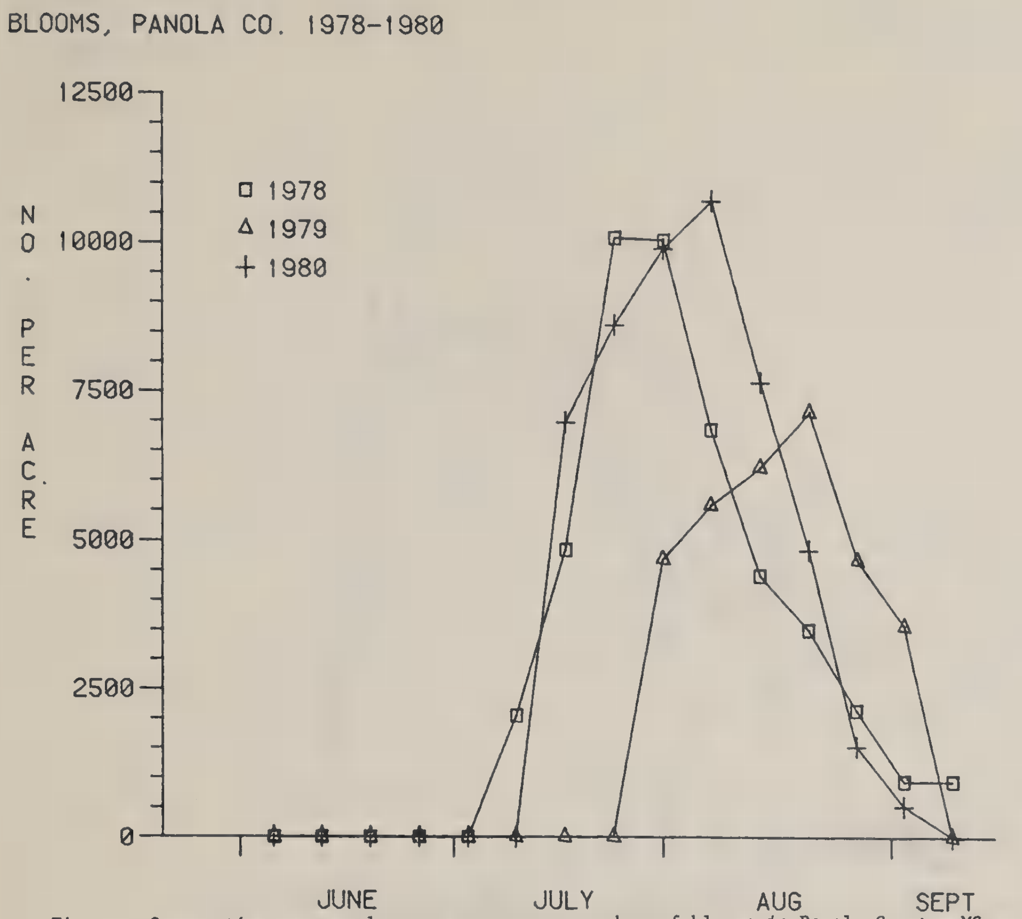


Fig. 45. Comparative, seasonal, per acre average number of blooms in Panola County, MS. - 1978, 1979, & 1980.

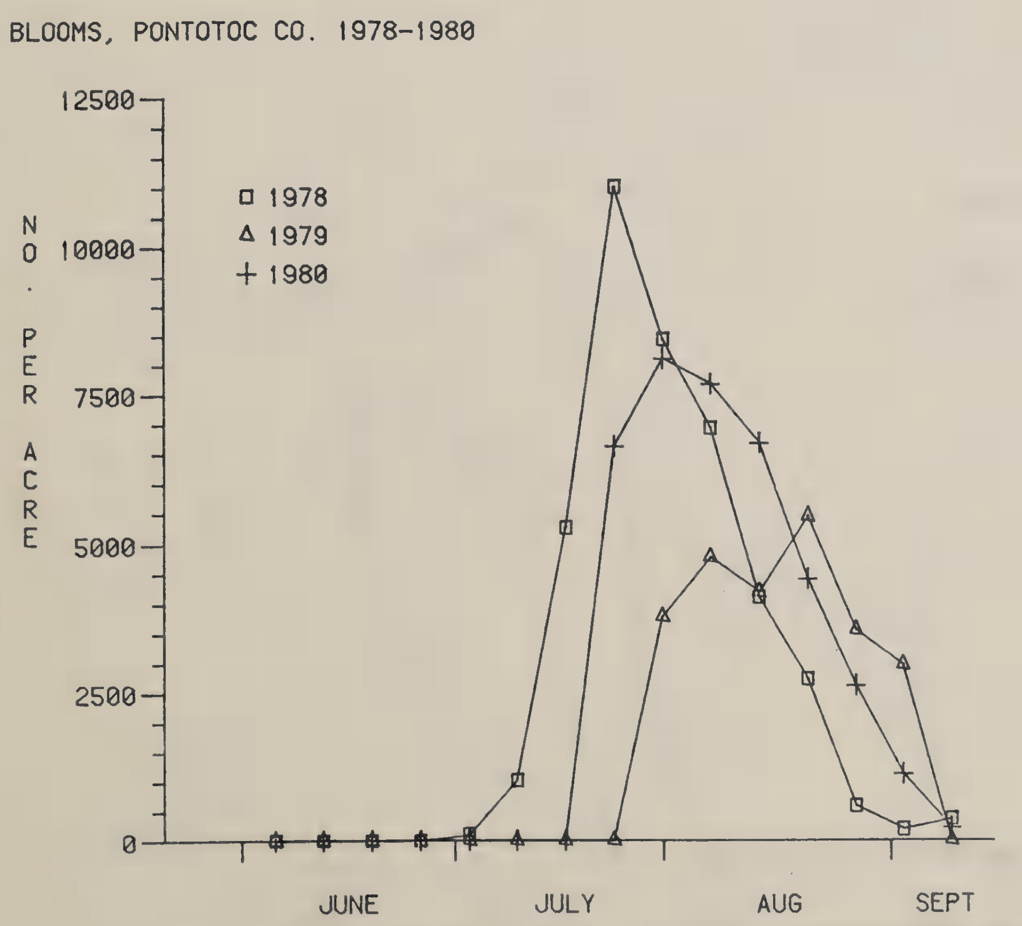


Fig. 46. Comparative, seasonal, per acre average number of blooms in Pontotoc County, MS. - 1978, 1979, & 1980.

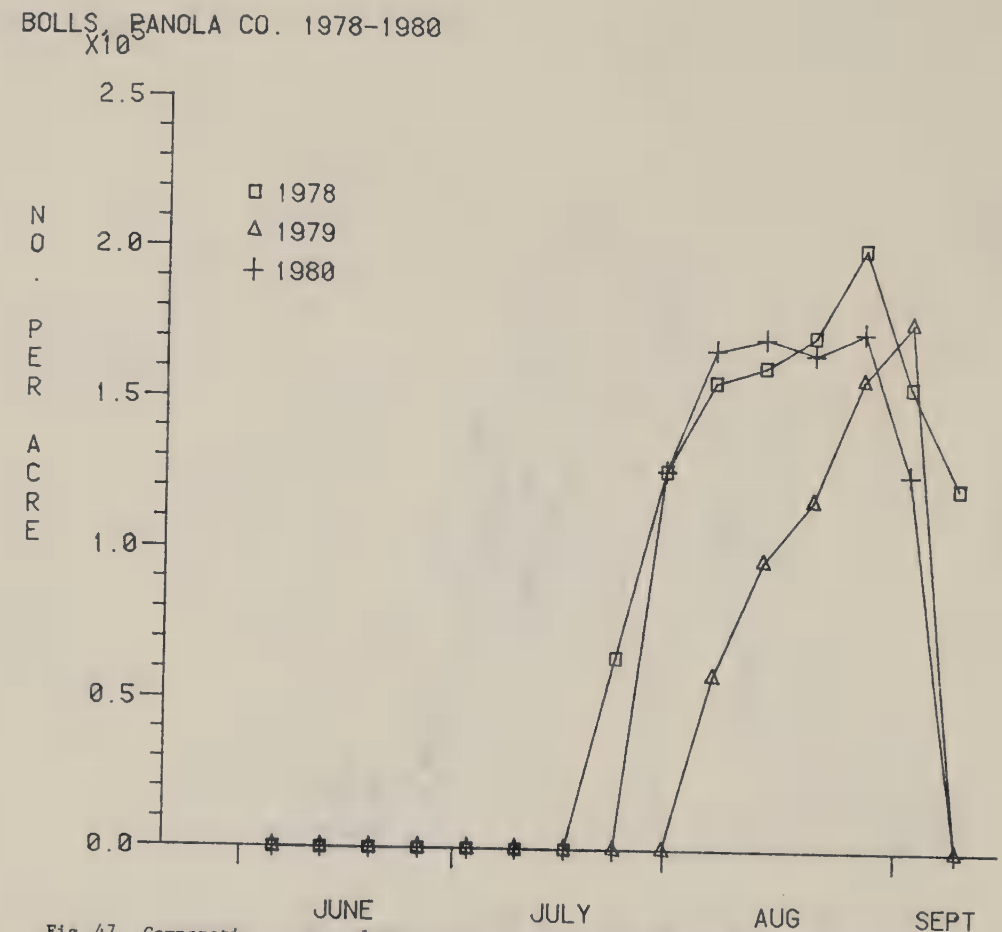


Fig. 47. Comparative, seasonal, per acre average number of bolls in Panola County - 1978, 1979 & 1980.

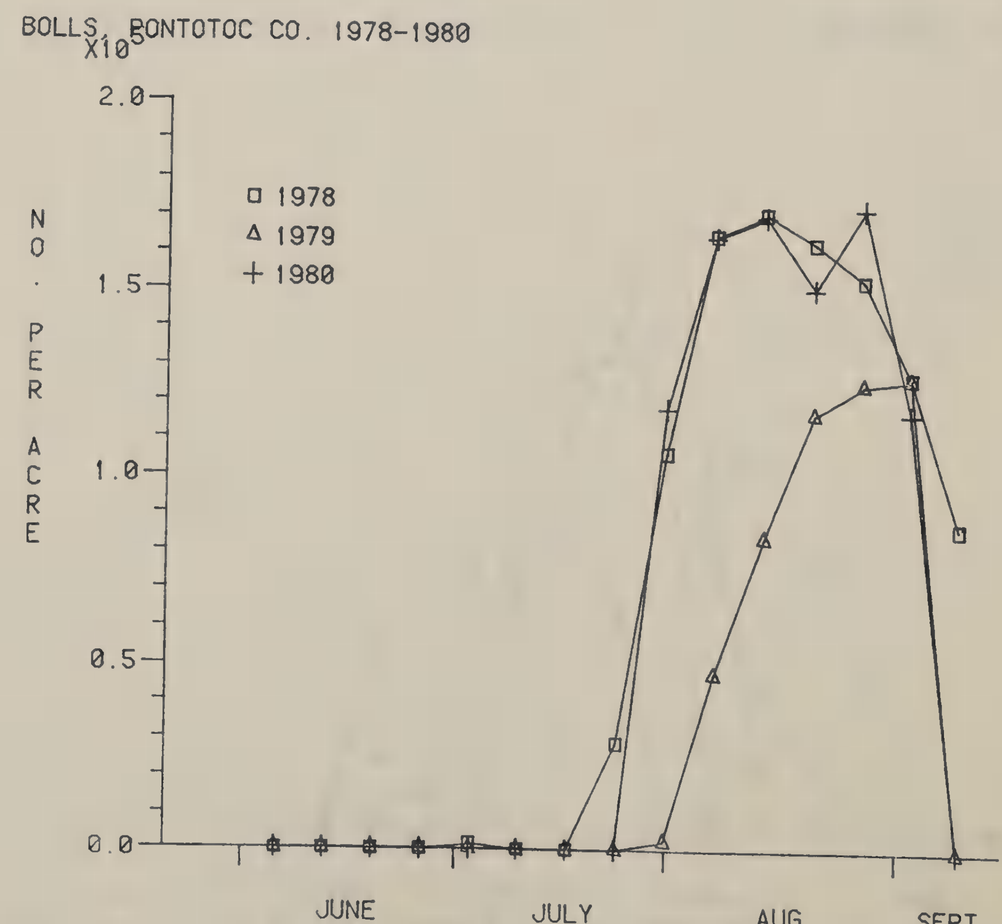


Fig. 48. Comparative, seasonal, per acre average number of bolls in Pontotoc County, MS.- 1978, 1979 & 1980.

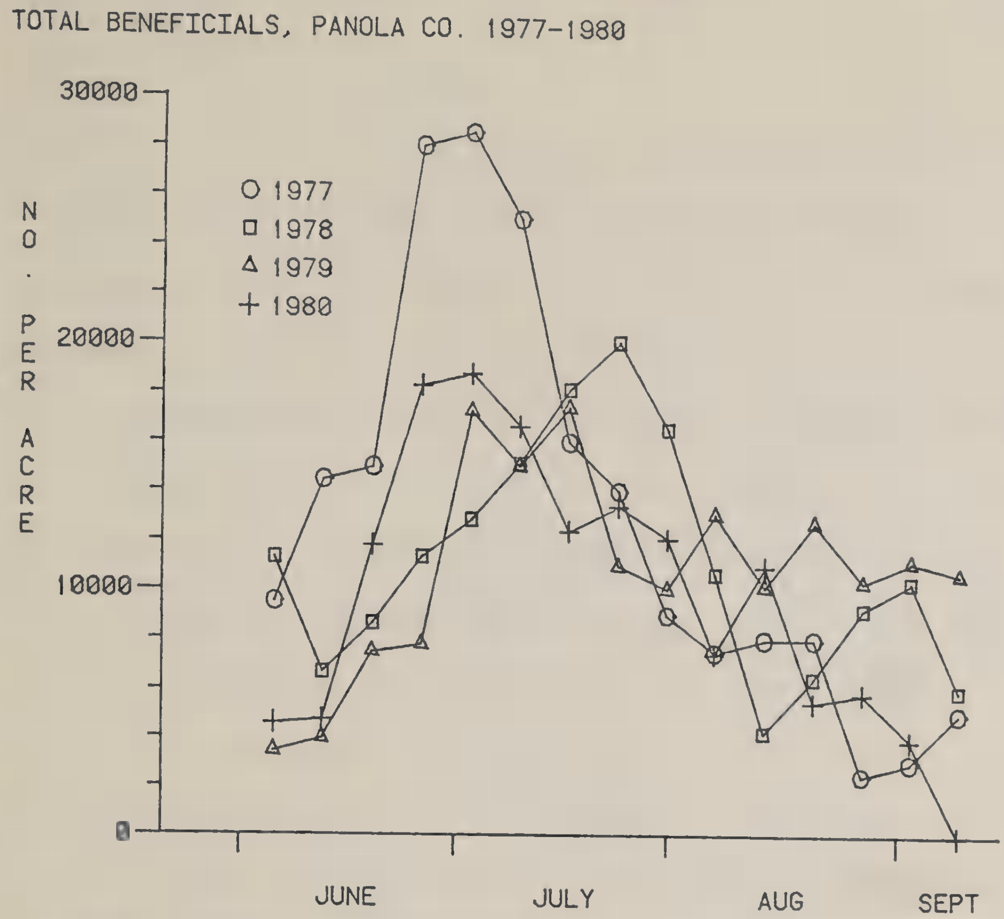


Fig. 49. Comparative, seasonal, per acre total beneficial arthropod populations based on D-Vac® samples in Panola County, MS. - 1977, 1978, 1979 & 1980.

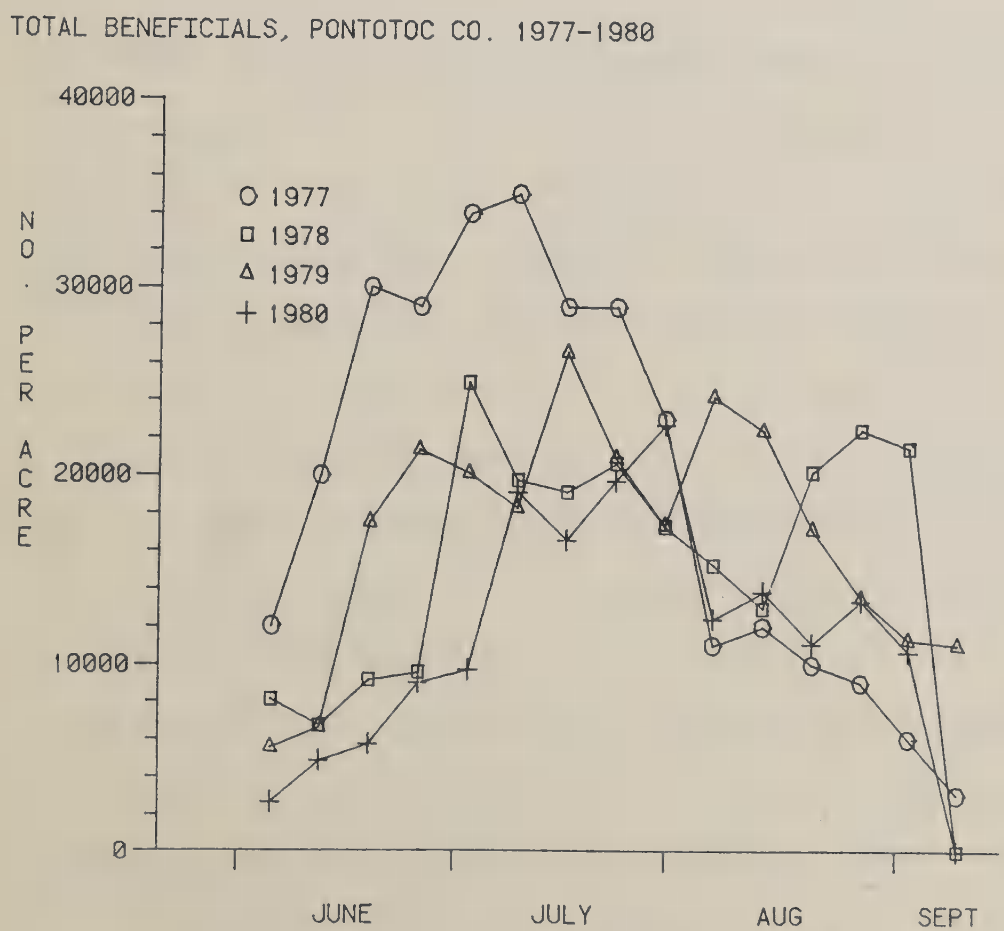


Fig. 50. Comparative, seasonal, per acre total beneficial arthropod populations based on D-Vac® samples in Pontotoc County, MS - 1977, 1978, 1979 & 1980.

Evaluation of Biological Success

The Optimum Pest Management (OPM) Trial was conducted in Panola County, Mississippi, under the supervision of the Mississippi Cooperative Extension Service and supported by several other state and Federal agencies. The OPM Trial was undertaken to compare area-wide management of the boll weevil and other cotton insects with a Current Insect Control (CIC) practices program, with the Boll Weevil Eradication (BWE) Trial, and with other options under consideration for beltwide implementation. Both trials were three-year programs (1978-1980) with 1977 as a base line year. Pontotoc County, Mississippi, was selected to represent a typical CIC program.

The objective of the OPM Trial was to demonstrate the operational capability, as well as test the technical components, of an area-wide cotton insect management program which maintains boll weevil populations below damaging levels by using insecticide applications late in the season for suppressing the numbers of diapausing boll weevils. Cooperation by cotton producers in the OPM area was voluntary, but incentives made participation desirable. By suppressing the boll weevil population with 4 diapause insecticide applications during September and October, the need for inseason insecticide treatments the next year was delayed through the period when use of insecticides would create the greatest disruption of beneficial arthropods. These disruptions can induce outbreaks of bollworms and tobacco budworms. Diapause insecticide applications were paid for with USDA funds and administered by the Mississippi Cooperative Extension Service.

Highly trained Extension pest management specialists actually conducted the OPM Trial. In addition to implementing the technical components of the Trial, they provided assistance to growers, consultants, aerial applicators, and others involved in related activities. Grower participation

required that their cotton be scouted weekly and a report filed with the Extension Service. Growers had the option of scouting the crop themselves, using private consultants, or employing scouts provided by the Panola County Extension Pest Management Society. Whatever the case, the Extension pest management specialists provided the training through pre-season workshops and follow-up training throughout the season. Panola County growers participated at the rate of 98.7, 99.6, and 99.7% of their acreage for 1978, 1979, and 1980, respectively.

In addition to diapause boll weevil control and regular scouting, and use of boll weevil pheromone traps were used to survey the weevil populations. Approximately 1,500 peripheral (border of the field) pheromone traps were operated between April 15-July 15 at a ratio of 1 trap to 20 acres of cotton each year of the trial to survey individual fields for possible damaging weevil infestations. Cotton growing areas within Panola County which showed an average trap capture of 45 weevils per trap per week during May were designated as possible candidate areas for the pinhead square application. During the entire 3-year program, only 57 acres needed a pinhead square application. These infestations occurred during the final year close to the county border and near cotton not included in any of the suppression efforts.

The pheromone trapping was continued during the fall as an additional monitoring activity. Since all fields were automatically treated for diapausing weevils, the fall trap catches were not used to make control recommendations.

Through the use of diapause applications and precise monitoring of boll weevil activity with pheromone traps, significant weevil suppression was attained. In the spring of 1979 and 1980, weevil captures in traps were 78 and 94% lower, respectively, in Panola than in Pontotoc County.

Inseason control utilized natural control factors for the management of pest species with emphasis on conservation of beneficial arthropod species. Most of the time, natural control agents effectively regulate bollworm and tobacco budworms during their first and second generations in cotton if disruptive insecticide treatments are not applied. Of course, the scouting program closely monitored pest population levels, and treatments were recommended when thresholds were exceeded. Insecticide applications in Panola County for control of bollworms/tobacco budworms during the growing season averaged 3.3 per season during the 3-year program as compared to 8.6 applications per season for the 3 years prior to the program. An overuse of insecticides probably occurred in Panola County in 1977 prior to the OPM program.

Beneficial insect populations were similar in the two counties during the four years. Beneficial insect populations received much more consideration from consultants and growers after they became aware of the OPM Research Team work in 1977. Since most beneficial arthropod populations were similar in 1979 and 1980 to those in 1978, the boll weevil diapause control treatments applied in the fall of 1978 and 1979 apparently had little adverse effect on such populations developing in cotton the following year.

The OPM Trial provided an opportunity to test the value of the collective efforts of many agencies and groups working together to suppress and manage insect populations on an area-wide basis. The presence and efforts of well-trained Extension pest management specialists within the Trial area working closely with producers, private consultants, aerial applicators, county Extension personnel, and others, resulted in a unified effort by all the cooperators.

Diapause boll weevil control, combined with the use of boll weevil pheromone traps for survey, regular scouting, and early-season insecticide applications only as needed, prevented the need for mid-season insecticide applications for the boll weevil. Therefore, the OPM trial accomplished its objective and was considered to be a technical and biological success.

CONSIDERATIONS FOR BELTWIDE BOLL WEEVIL MANAGEMENT PROGRAMS

Estimated Biological Impacts in Mississippi and North Carolina

Current Insect Control (CIC) practices for cotton insect management to a large degree depend upon the use of insecticides to protect growers from major losses due to insects. Alternative insect management approaches are under consideration because: (1) Non-target organisms such as bees, ants, birds, insect predators, and parasites, etc., are adversely affected by repeated insecticide treatments; (2) Potential pests are sometimes elevated to pest status by the elimination or reduction of natural control agents by repeated insecticide applications. (In much of the Cotton Belt, *Heliothis* spp. on cotton are often elevated to major economic pest status due to insecticide applications for boll weevil control, according to Ewing and Ivy 1943, and Newsom and Smith 1949); (3) The repeated use of insecticides may result in the target pest developing resistance to the insecticide. (*Heliothis virescens* became a major pest in some areas due to resistance to organophosphate insecticides according to Harris 1972); (4) Current Insect Control practices require the perpetual year-in/year-out application of insecticides. (This has major long-range adverse environmental implications [Carson 1962]).

One alternative to CIC practices presently under consideration, not requiring annual applications of insecticide for the boll weevil, is beltwide Boll Weevil Eradication (BWE). A second alternative requiring annual, carefully timed insecticide treatments to suppress diapausing boll weevil populations on an area-wide basis is the Optimum Pest Management (OPM) approach. A BWE Trial was conducted in northastern North Carolina and southeastern Virginia in 1978, 1979, and 1980. An OPM Trial was conducted simultaneously in Panola County, Mississippi.

The results of the BWE and OPM Trials are found above and in Attachment C and B. 15, respectively. The native boll weevil population, at a probability of >0.9983, was eradicated from the N.C. Trial Evaluation Area in 1979-1980. The OPM Trial in Mississippi reduced boll weevil population to sub-economic levels during the early fruiting stages of the cotton plant. During this period, beneficial arthropod populations were not disrupted by insecticidal treatments for weevils, allowing parasites and predators to provide natural control for Heliothis spp.

The anticipated major benefits from BWE are the long-term reduction in the need for insecticide treatments to control cotton insects and the subsequent increase in yields resulting from decreased losses to boll weevil and bollworm. A reduction in insecticide applications and increased yields are anticipated with OPM though not to the extent as with BWE. A perpetual need for chemical insect control is implied in OPM.

The insecticide use patterns associated with the biological evaluation sample fields in the North Carolina BWE and the Mississippi OPM Trials and the two CIC areas associated with both Trials are presented in Table 13. Pre-program averages for insecticide applications were 9.9 and 11.1 for the BWE and CIC areas, respectively, in North Carolina (Attachment B. 19). Expert opinion indicates 7.4 and 8.7 insecticidal treatments per acre would be the 10-year averages in the BWE and CIC areas of North Carolina (Appendix H to Overall Evaluation Report). An 88% reduction occurred in the numbers of insecticide treatments in 1980 compared to preprogram average in the BWE Trial Area. A corresponding 25% reduction occurred in the CIC area of North Carolina (Table 13). For this same period, a farmer survey indicated an 89% reduction in the BWE and 39% in the CIC areas in North Carolina (Attachment B. 19).

An average of 6 insecticide treatments per acre, including 4 boll

Table 13.--Number of insecticide applications for bollworm (wm) and boll weevil (wv) (including diapause) in the BWE, and OPM Trials, and the CIC areas associated with both trials - Biological Evaluation Data.

	North Carolina						Mississippi					
	BWE[1]			CIC[2]			OPM[3]			CIC[4]		
Year	Wm	Wv	Tot	Wm	Wv	Tot	Wm	Wv	Tot	Wm	Wv	Tot
Pre-program (avg)			9.9[5]			11.1[5]			8.4[6]			7.5[6]
1977	7.7	0.4	8.1	11.6	0.0	11.6	3.9	0.0	3.9	1.6	0.0	1.6
1978	3.7	6.2	9.9	9.4	0.0	9.4	1.9	4.0	5.9	0.9	0.0	0.9
1979	2.1	0.4	2.5	7.1	0.7	7.8	1.6	4.0	5.6	0.6	0.0	0.6
1980	1.2	0.0	1.2	6.3	2.0	8.3	2.4	4.1	6.5	1.0	1.2	2.2

1/ Values include those counties in the Evaluation Area excluding Chowan County.

2/ Scotland and Robeson counties only.

3/ Panola County

4/ Pontotoc County

5/ 1974-1977 avg

6/ 1967-1977 avg

weevil diapause treatments, were applied in the Mississippi OPM Trials (Table 13). The accompanying CIC area averaged 1.2 treatments for the same period. The number of insecticide applications in the CIC area in Mississippi was lower than in the OPM area for several reasons. Beneficial arthropod populations were approximately 50% higher in the CIC area than in the OPM area, thus greater natural control was provided in the CIC area. Another important factor was that growers in the CIC area were willing to tolerate more insect damage than in the OPM area.

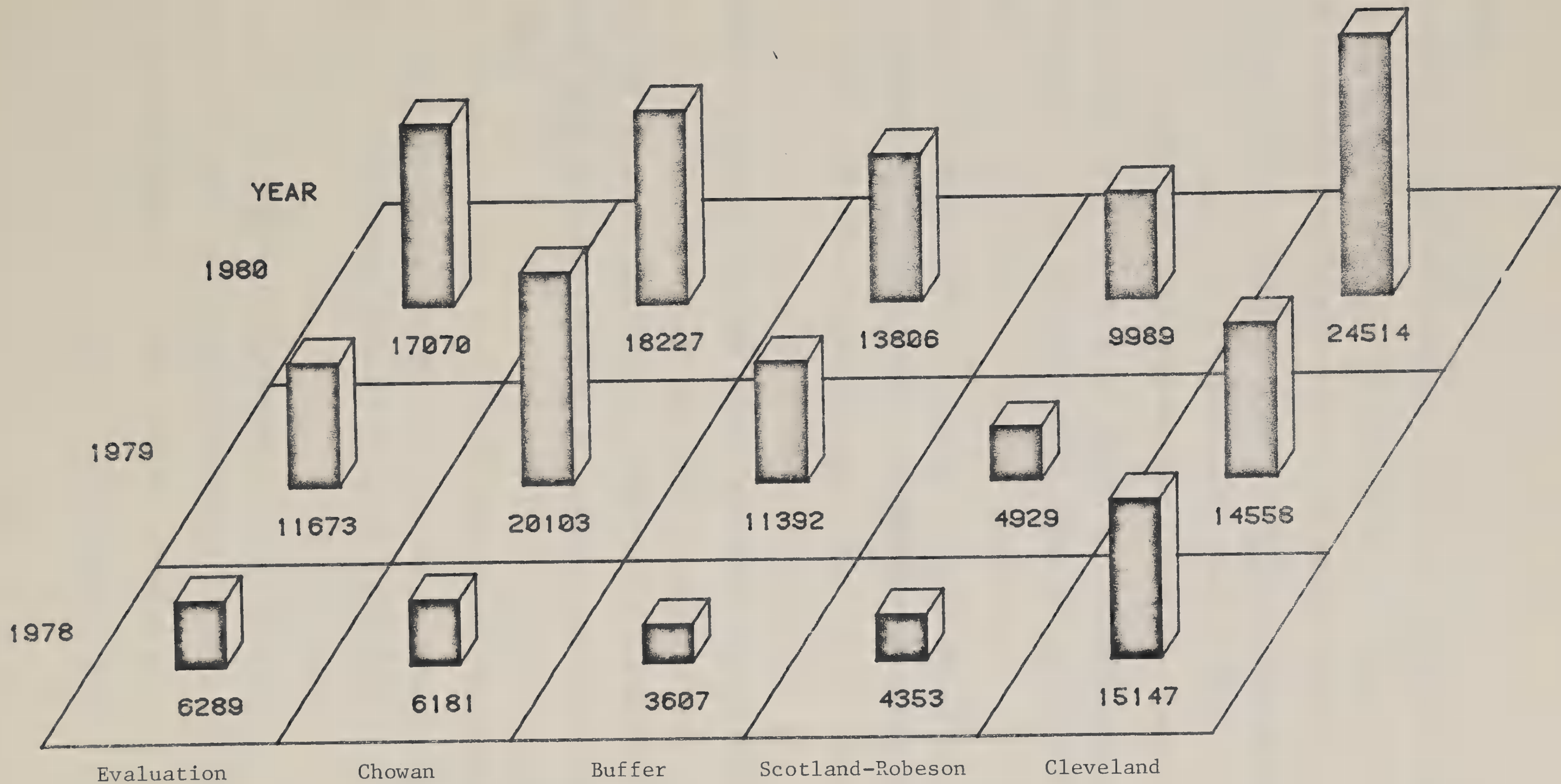
The major differences in the number of insecticide applications within the BWE and OPM trials occurred after insecticide treatments for the boll weevil were no longer required in the BWE area of North Carolina (Table 13). The number of insecticide treatments declined to 1.2 in the BWE by Year 3 of the trial but remained approximately 6 in the OPM Trial.

The interaction between the reduction in insecticide applications associated with the eradication of the boll weevil and the accompanying increase in the population of beneficial arthropods are essential factors in evaluating the benefits of BWE compared to OPM or CIC.

Biological evaluation data were collected from 5 areas in North Carolina as described above and in Attachment E.

The last insecticide applications for boll weevil in Chowan County and the Evaluation Area occurred in 1978 and 1979, respectively. Based on biological evaluation data (Attachment E, Table 6), insecticide applications in the Evaluation Area and Chowan County decreased from 9.9 to 1.2 and from 10 to 0.64, respectively, between 1978 and 1980. Within the same period, average weekly populations of beneficial arthropods in July and August increased from 6,289 to 17,070 in the Evaluation Area and from 6,191 to 18,227 in Chowan County (Figure 51 this report). Of those fields sampled

Fig. 51. Weekly average number of beneficial arthropods per acre for the five areas sampled July through August in 1978, 1979, and 1980.



during 1980 in the Evaluation Area and in Chowan County, 41 and 60%, respectively, required no insecticide treatments for bollworm. Evaluation Area fields receiving insecticide treatments required an average of 2 applications. Once broad-spectrum insecticides are applied, damageable fruit must be continuously protected by additional insecticide treatments until the insect threat is past or the fruit is matured.

In Cleveland County, North Carolina (CIC area), beneficial arthropod populations (Figure 51) in those fields sampled twice weekly, averaged approximately 18,000 per week during July and August for the 3-year period. Insecticide treatments for bollworm were zero in 1978 and 1979. However, in 1980, two of the sampled fields received insecticide treatments for boll weevil during the early fruiting stage (July 16). Subsequently, 6 additional treatments for boll weevil and bollworms were applied. Bollworm damage in these two fields were more than 4 times as great as in untreated fields in Cleveland County. Beneficial populations were near zero throughout the period of insecticide treatments in the treated fields.

The number of insecticide treatments applied in the Buffer Area and in Scotland-Robeson counties has declined somewhat between 1978 and 1980 (Attachment E, Table 6). This reduction is due, in part, to the shift from organophosphate insecticides to synthetic pyrethroids and the accompanying increase in application intervals. Beneficial arthropods have also increased during the same period (Figure 51) but not to the levels in the Evaluation Area and Chowan County.

The ability of beneficial arthropods to reduce the economic importance of bollworm in the relatively insecticide-free environment provided by BWE was illustrated in North Carolina. Much of the insect control needed to keep bollworm damage at subeconomic levels for 1979 and 1980 was provided by

beneficial arthropods in the Evaluation Area and in Chowan County, and for 1978, 1979, and 1980 in Cleveland County.

According to Carlson and Suguiyama (Attachment B. 19), "analysis of various data sets has not been able to directly measure effects of early season weevils on yields." However, they reported for North Carolina, "one indirect measure of yield effects from weevil removal is the effect of delayed insecticide application on yields." Based on the analysis of 38 experiments conducted at Rocky Mount, N. C., by the North Carolina State University, "each ten-day delay in treatment initiation increases yields by about 70 pounds of lint cotton."

Weather, soil, fertilization, and cultural practices generally have more impact on yield than factors associated with BWE, OPM, or CIC methods of insect control. Through simulation modeling, Simpson and Parvin (Attachment B. 18) projected the effects of these three insect control tactics on yield (Table 14). The OPM-BWE strategy in Mississippi results in a 24-31 pound increase in lint cotton over CIC. The OPM-BWE strategy in Mississippi approximates the BWE program in North Carolina. The OPM option was not projected to North Carolina.

Table 14.--Estimated per acre cotton lint yield increases by region and by strategy for Mississippi.

	DELTA	NORTH CENTRAL	SOUTH	NORTHEAST HILLS	NORTHEAST PRAIRIE
CIC	BASE	BASE	BASE	BASE	BASE
OPM	+6[1/]	+22	+22	+18	+18
CIC-BWE	+4	+23	+24	+19	+19
OPM-BWE	+7	+29	+31	+24	+24

1/ Increase in the lbs per acre cotton lint yield.

Inputs into Estimated Beltwide Biological Impacts of Alternative Programs

Information obtained partially by BET from the North Carolina BWE and Mississippi OPM Trials, along with additional information from other sources, was utilized in a Delphi process to evaluate the impact of possible beltwide implementation of several insect management programs. The Delphi questionnaire, developed with the assistance of the BET, assessed insect control costs and cotton yield for the 35 boll weevil infested sub-regions of the U.S. Cotton Belt.

The Delphi approach provides for systematic collection of information from experts. It involves a high degree of intuitive judgment based on experience and other insights. A resource group (Appendix H, Delphi Results), including among others 8 BET members and consultants possessing expertise in various aspects of cotton insect management, was organized to provide additional information to the panel of experts participating directly in the Delphi process. This resource group assisted Delphi panel members by clarifying and by providing followup analysis of the interim Delphi results.

Considerable background resource information was prepared by BET and made available to Delphi panel members for technical areas having significant impact on insect control costs and yields. The following specific information was provided:

1. Cotton varieties - Modified cotton cultures, including the use of rapid fruiting and/or insect resistant varieties, offer considerable potential for reducing losses due to insects (Attachment B. 4).
2. Projections on the average percentage of cotton acreage for each of the 35 sub-regions in an average climate year that would need to be included

under OPM with fall diapause treatments to maintain the boll weevil as a sub-economic pest (Appendix H).

3. Effectiveness of pyrethroids against the boll weevil (Attachment B. 10).
4. Effects of predators on the bollworm and tobacco budworm (Attachment B. 5).
5. The dollar value of beneficial insects on cotton (Attachment B. 5).
6. Estimates of the effects of alternative management programs on cotton yields and insect control (Beatriz Escara 1979, M.S. Thesis, Mississippi State University, Mississippi State, MS).
7. Conceptual yields and insecticide use (based on simulations) from North Carolina (G. H. McKibben, E. P. Lloyd, unpublished).
8. Use of simulation modeling for estimating impacts of alternative insect control strategies on yield and insecticide use (G. H. McKibben and W. A. Dickerson, unpublished).

Extrapolation of Technology Beltwide

The OPM and BWE Trials have been judged to be technical and biological successes, i.e., in the OPM Trial no inseason applications of insecticide were required for boll weevil control, and in the BWE Trial "native" boll weevils were eradicated from the Evaluation Area with a probability level of >0.9983. Moreover, certain of the procedures used in these Trials should be generally acceptable beltwide, at least in principle, for instance, (1) 99 to 100% participation by producers, i.e., total population management, (2) more intensive monitoring with traps and by field inspection, (3) elimination of the use of broad-spectrum insecticides for inseason control of boll weevil, (4) conservation of populations of natural enemies, and (5) reduction in amounts of insecticide used for control of bollworms and budworms. But

there are some uncertainties associated with beltwide extrapolations, particularly in regard to the adequacy of proposed barrier zone(s) set up to prevent reentry of boll weevils. For instance, between-season survival of the boll weevil is altered in this zone which grows the only U.S. cotton in a subtropical environment. Hibernation may not be required, and at least two alternate hosts unique to U.S. distribution of the boll weevil occur here. These factors have been studied and may not cause complications.

The various survey and suppression technologies tested in Trials would likely require some modifications in different areas of the Cotton Belt because of the existence of different environments and different cultural practices. However, the availability of a highly sensitive detection and monitoring system using pheromone traps, even at the lowest population level at which reproduction occurs, provides a means of employing available boll weevil suppression methods promptly and in a highly efficient manner. Thus, there is no reason to believe that the various technologies used in the Trials would be any less effective in other weevil infested areas of the Cotton Belt, with the possible exception of south Texas, than they were in the Trial areas, if these technologies are properly applied.

GLOSSARY

The following terms are defined as used in the boll weevil/cotton insect management programs.

Adult. The mature arthropod life stage.

Arthropods. Those animals possessing a segmented body, bilateral symmetry, paired jointed appendages usually terminating in claws, chitinous exoskeleton, ventral nervous system and dorsal heart.

Beneficial insects. Those insects that predate or parasitize pestiferous arthropods.

Boll Weevil Eradication Trial (BWET) conducted in southeastern Virginia and northeastern North Carolina from 1978-1980.

Current Insect Control (CIC). Insect control as now practiced by individual producers with the current level of Extension education funding and private consultant services.

Current Insect Control with Boll Weevil Eradication (CIC-BWE). Assumes a boll weevil eradication program has been implemented and the Extension Education program is funded at the current level.

Control. To check or regulate, to keep within limits.

Diapause. A physiological condition which enables boll weevils to survive the winter or other adverse, between-cotton season conditions. This condition in the boll weevil is recognized by an increase in fat bodies and by atrophy of gonads.

Insects. Hexapods...those arthropods that possess 3 pairs of legs and 3 body segments.

Larvae. The immature stages, between the egg and pupa, of an insect having complete metamorphosis.

Modified Optimum Pest Management (MOPM). Funds for increased Extension education are included as a component to facilitate the transfer of new technology to individual growers.

Native boll weevils. A population of boll weevils established in a geographic area over one or more cotton seasons and overwintering successfully in that area.

Optimum Pest Management (OPM). Insecticide treatments applied for suppression of diapausing boll weevils in the fall and early season insecticide treatments as needed in an area-wide program to prevent damaging levels of boll weevils from developing prior to onset of pressure from *Heliothis* spp.

Oviposition. The depositing or laying of eggs by an arthropod.

Parasites. Those arthropods that live in or on the body of another arthropod (its host), at least during part of its life.

Pheromone. Substances that are secreted by an animal to the outside and cause a specific reaction in a receiving individual of the same species. The boll weevil pheromone causes a sexual attractancy of the female to the male. It also is an aggragating stimulus. The artificial boll weevil pheromone is known as grandlure.

Pinhead square. Cotton bud too small to support boll weevil reproduction.

Predators. Those arthropods that attack, kill and consume other arthropods.

Pupa. The stage of development between the larva and the adult in insects with complete metamorphosis...a non-feeding and usually inactive phase.

Simulated. Data generated by mathematical or computer models which is a representation of the actual real world event.

Spider. An arthropod possessing 2 body segments (the abdomen and cephalothorax), 4 pairs of legs, an unsegmented abdomen, spinnerets and the antennae modified into organs of prehension.

Stalk destruction. To mow or cut the plant material remaining in the cotton field after harvesting.

Technology. The entire body of methods and materials used to achieve an objective.

Uniform planting date. Planting a crop in a community as close as possible to a given date. This is done to avoid field of widely varying phenology which can concentrate pest on those areas in the most desirable condition.

Zero native boll weevils. No boll weevils in an area other than those that may have migrated in from another area during the current cotton growing season.

ABBREVIATIONS

BET. Biological Evaluation Team.

BWE. Boll Weevil Eradication.

BWET Boll Weevil Eradication Trial.

CIC. Current Insect Control.

CIC-BWE. Current Insect Control with Boll Weevil Eradication.

MOPM-BWE. Modified Optimum Pest Management with Boll Weevil Eradication.

OPM. Optimum Pest Management.

OPM-BWE. Optimum Pest Management with Boll Weevil Eradication.

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ATTACHMENT A

BIOLOGICAL EVALUATION PLAN

FOR

ALTERNATIVE BELTWIDE COTTON INSECT MANAGEMENT PROGRAMS

I. OBJECTIVES

A. To evaluate the degree of biological success of the Optimum Pest Management (OPM) Trial and the Boll Weevil Eradication (BWE) Trial.

B. To develop the relationships of the detrimental and beneficial cotton arthropods to the environment, cultural practices, needs for insecticide applications, and resulting yield within the trial and adjacent areas.

C. To measure the impact under Current Insect Control (CIC), OPM, and BWE of the boll weevil, bollworm/tobacco budworm, and predators and parasites on insecticide usage and cotton yield in North Carolina and Mississippi.

D. To provide inputs needed to assist in the estimation of beltwide biological impacts of alternative boll weevil/cotton insect management programs, by regions.

II. SCOPE AND MAJOR COMPONENTS

In order to meet the objectives listed above, the Biological Evaluation Team (BET) will critically examine representative cotton fields from each of the trial areas (OPM and BWE) and from some nearby areas not included in the trials (CIC). Information gathered will include topography, soil type, and fertility conditions; surrounding habitat; weather data; crop history and plant growth characteristics; chemical applications; arthropod pest infestations; and counts of beneficials and other insects. Data collected on infestations in all fields within the trial areas by Mississippi Cooperative Extension

Service sponsored scouts in Panola County, Mississippi (OPM) and by APHIS personnel in North Carolina (BWE) will be reviewed and analyzed by BET.

Close attention will be given to interpreting boll weevil population counts, identifying sterile vs. wild weevils, interpreting long-range dispersal, and pinpointing sources of origin. The overall effects of the trials (immediate and long-range) on damage by other pests will also be considered (Objective A).

Arthropod populations within the cotton fields will be considered as dynamic communities. Data obtained on populations from direct observations and special sample techniques will be utilized to make recommendations on better pest and beneficial management schemes (Objective B).

The impact under CIC, OPM, and BWE on populations of the boll weevil, bollworms, and selected beneficials and the resultant effect on cotton yield and pesticide use (Objective C) will be specifically addressed with use of simulation models.

The timetable for estimation of beltwide impact has not been completely defined; however, some ideas of BET on joint responsibility are mentioned in "IV" below (Objective D).

In summary, the major components of the Biological Evaluation plan include biological evaluation of the trials, biological impacts of the trials in comparison with CIC, and estimation of beltwide biological impacts of alternative cotton insect management programs.

Major responsibilities include:

A. Develop analytical framework/model for technical evaluation of BWE and OPM.

B. Develop analytical framework/model to estimate the effect of OPM and BWE on insecticide use and yield for comparison with CIC

C. Collect biological data in trial areas and CIC areas for technical evaluation of trials and to validate trial area model for annual and three-year trial area evaluations.

D. Define CIC with assistance from EET and develop detailed biological specifications for the selected production subregions.

E. Conduct annual and three-year impact analysis and evaluation of data in trial areas.

F. Prepare quarterly, annual and final reports of results of biological evaluations.

III. PERFORMANCE CRITERIA

The BET will base its evaluation of the results of BWE on (1) an expected 10 percent or less of the trial acreage being infested by boll weevil during the second year with population levels on that acreage reduced to 3 or less weevils per acre; (2) zero native boll weevil infestations in the Trial Area after July 15 of the third year of the program operations, as determined by trapping survey and other available methods; (3) acceptable levels of bollworm and beneficial populations, and (4) acceptable levels of pesticide usage and yield.

The BET will evaluate OPM based on (1) maintenance of boll weevil and other pest populations below damaging thresholds; (2) maintenance of acceptable levels of beneficial arthropod populations, and (3) acceptable levels of pesticide usage and yield.

IV. AGENCY RESPONSIBILITIES

Two Research Teams (SEA and SAES cooperating), one in North Carolina and one in Mississippi, have been identified. These teams will collect the specific data required primarily for biological evaluation. Special consultants have also been identified and a cooperative agreement with Mississippi State University, Department of Agricultural Economics, privides the simulation modeling effort.

Compatible programs are being developed for storage and handling of operation and evaluation data in the North Carolina State University computer for the BWE Trial and in the Mississippi State University computer for the OPM Trial.

BET will assist in collecting data by regions on changes in cotton plant/arthropod pest relationships and relative value of beneficial populations. Region-wide data available from spray groups, aerial applicators, gin operators, farmers, farmer organizations, or in any way involving extensive survey by questionnaires will not be considered a direct BET responsibility. BET will assist in phrasing questions which have biological implications and interpreting the answers returned on questionnaires. BET will also assist in locating by regions the individuals most knowledgeable of CIC and will join with EET to interview these experts.

ATTACHMENT B

COTTON INSECT MANAGEMENT WITH SPECIAL REFERENCE TO THE BOLL WEEVIL
(a technical monograph in preparation)

Edited by
R. L. Ridgway, E. P. Lloyd, and W. H. Cross

The following chapters of this technical monograph are in peer review process. If you have specific need of any of the material covered before publication, please contact the individual authors. References in the Biological Evaluation Report to "B.1" etc indicate these chapters as numbered below.

I. Introduction

1. The Evolution of Cotton Insect Management
   R. L. Ridgway and E. P. Lloyd

2. The Cost of Insecticides Used on Cotton in the United States
   F. T. Cooke, Jr. and D. W. Parvin, Jr.

3. Ecology of Cotton Insects: Special Reference to the Boll Weevil
   W. H. Cross

II. Suppression Components

4. Host Plant Resistance and Modified Cotton Culture
   L. N. Namken, M. D. Heilman, J. N. Jenkins, and P. A. Miller

5. Entomophagous Arthropods
   J. R. Ables, J. L. Goodenough, A. W. Hartstack, and R. L. Ridgway

6. Microbial Agents
   Marion R. Bell

7. Boll Weevil Sterility
   James E. Wright and Eric Villavaso

8. Pheromone for Survey and Detection
   E. P. Lloyd, G. H. McKibben, J. E. Leggett, and A. W. Hartstack

9. Insect Growth Regulators
   D. L. Bull, J. R. Ables, and E. P. Lloyd

10. Insecticides for Control of Cotton Insects
    C. R. Parencia, T. R. Pfrimmer, and A. R. Hopkins

ATTACHMENT C

The Boll Weevil Eradication Trial

Milton Ganyard, Justin Dillier and J. R. Brazzel

SUMMARY

The native boll weevil population was eliminated in July of 1979 in the evaluation zone. A total of 6 isolated boll weevil captures and one localized reinfestation of 10 boll weevils have occurred since that time. Isolated captures may continue to occur. However, no suppression activities are planned in the evaluation zone unless there is evidence of a need to eliminate a localized reinfestation.

Growers in the evaluation zone reduced the number of insecticide applications required for other insects (primarily bollworm) from an average of 7.5 a year in 1974-77 to 3.5 in 1978, 2.2 in 1979 and 1.2 in 1980. Total applications for all insect pests during 1974-77 averaged 10 per year. This reduction of insecticide use is due to (1) removal of the boll weevil from the system, (2) elimination of biologically disruptive boll weevil insecticide applications, (3) population increases of beneficial species and (4) increased grower confidence in scouting and IPM principles.

While acreage during 1978 showed a substantial reduction from the pre-trial acreage (1977) there was a strong rebound in 1979 and 1980. Acreage in the trial area in 1980 was about 87% of the pre-trial level (1977) while the remainder of NC was at about 65% of its 1977 level. When this report was prepared, there were strong indications that an even greater difference in acreage rebound would occur in the eradication area in 1981.

INTRODUCTION

The NC-VA Boll Weevil Eradication Trial (BWET) was conducted to test and demonstrate technological and operational capability to eradicate the boll weevil from a geographically specified area. BWET was a three-year operation which started in early 1978 and ended December 31, 1980. A concurrent optimum pest management trial was conducted in MS to test and demonstrate ability to manage boll weevil and other cotton pests.

The United States Department of Agriculture, Animal and Plant Health Inspection Service (USDA, APHIS) had lead responsibility for the Boll Weevil Eradication Trial (BWET). Cooperators in the trial were the North Carolina Department of Agriculture (NCDA), the Virginia Department of Agriculture and Commerce (VADAC) and all cotton producers northeast of Fayetteville, NC.

Costs of the BWET were shared by participating groups on a per acre basis as follows: Cotton producers - 50%, USDA-APHIS - 25% and NCDA and VADAC - 25%.

The BWET area encompassed 29 counties (21 commercially produced cotton in 1980) and 8,400 square miles, spanning from a few miles north of Fayetteville, NC into southern VA. In 1980 there were 34,041 commercial cotton acres, 2,229 cotton fields and 408 cotton growers.

History of Major Events Leading to the NC-VA Boll Weevil Eradication Trial

The first direct step toward boll weevil eradication occurred with the execution of the Pilot Boll Weevil Eradication Experiment (PBWEE) in 1971-73. That experiment covered all or parts of 30 counties in south MS, 5 parishes in LA and 2 counties in AL. A report entitled Boll Weevil Suppression Management and Elimination Technology - Proceedings of a Conference, February 13-15, 1974, Memphis, Tennessee (ARS-S71) dealt with events leading to the PBWEE, status of technology, execution, results, evaluation, concurrent research and various conclusions of the experiment. At this conference it was generally agreed that certain technological refinements and a further test of operational ability were needed before a decision could be made on the advisability of beltwide eradication.

At a beltwide meeting of cotton leaders held in Memphis on October 1, 1974, it was decided to conduct an eradication trial in a suitable location whenever artificial mass rearing and sterility procedures for the boll weevil were adequately developed. The trial was to be conducted in a location where sufficient geographical isolation from adjacent infested cotton acreage would allow for proper evaluation of an attempt to eliminate a native population from the prescribed trial area.

Subsequent meetings were held with cotton interests in NC, OK and TX to determine which region of the cotton belt would fit the economical, biological and logistical criteria needed to conduct the trial. It was decided that a smaller acreage with a lower associated program cost, could be isolated at the eastern region.

In 1976 Congress stipulated that each of the three states to be involved must pass and implement the necessary legislation and demonstrate to appropriate congressional committees that they were legally and financially prepared to fulfill their responsibilities under the program. Upon fulfillment of these requirements the USDA would be funded to conduct a trial only if participating cotton producers and state legislatures funded 75% of the costs to conduct the trial. Thus USDA could only pay 25% of trial operations costs.

Regulatory authority to conduct the trial was obtained through the passage by the General Assembly of the State of NC of the Boll Weevil Eradication Act of 1975 and passage in 1976 of Article 6 of the VA Pest Law by the General Assembly. Proposed trial plans included cotton acreage in SC. Hence, the General Assembly of the State of SC passed the South Carolina Boll Weevil Eradication Act in 1976. Adequate isolation of cotton acreage for the trial was later obtained in VA and NC and operations were not required in SC other than monitoring of boll weevil populations.

In 1976 the General Assembly of the State of NC funded the NC Department of Agriculture to support 25% of the trial operational costs. The VA Commissioner of Agriculture and Commerce was able to provide sufficient funds for supporting 25% of the costs without special appropriations.

In December 1976, growers in NC affirmed, through a referendum, their approval for the trial to be conducted and to pay 50% of the costs. Approval for the trial in VA was obtained through a public hearing.

Funding by Congress for the USDA portion of the Trial costs was received during FY-1977 through FY-1980. FY-1977 funds were used to set up and support the evaluation and R&D support activities. Appropriations in FY-1978 through FY-1980 supported the cooperative trial.

Organization and Management Scheme

The Secretary of Agriculture has overall responsibility for USDA boll weevil program policy. During the conduct of the eradication and management trials all involved USDA agencies were organized in a broadly based management scheme to ensure appropriate participation by all planning, implementation and evaluation groups (Figure 1).

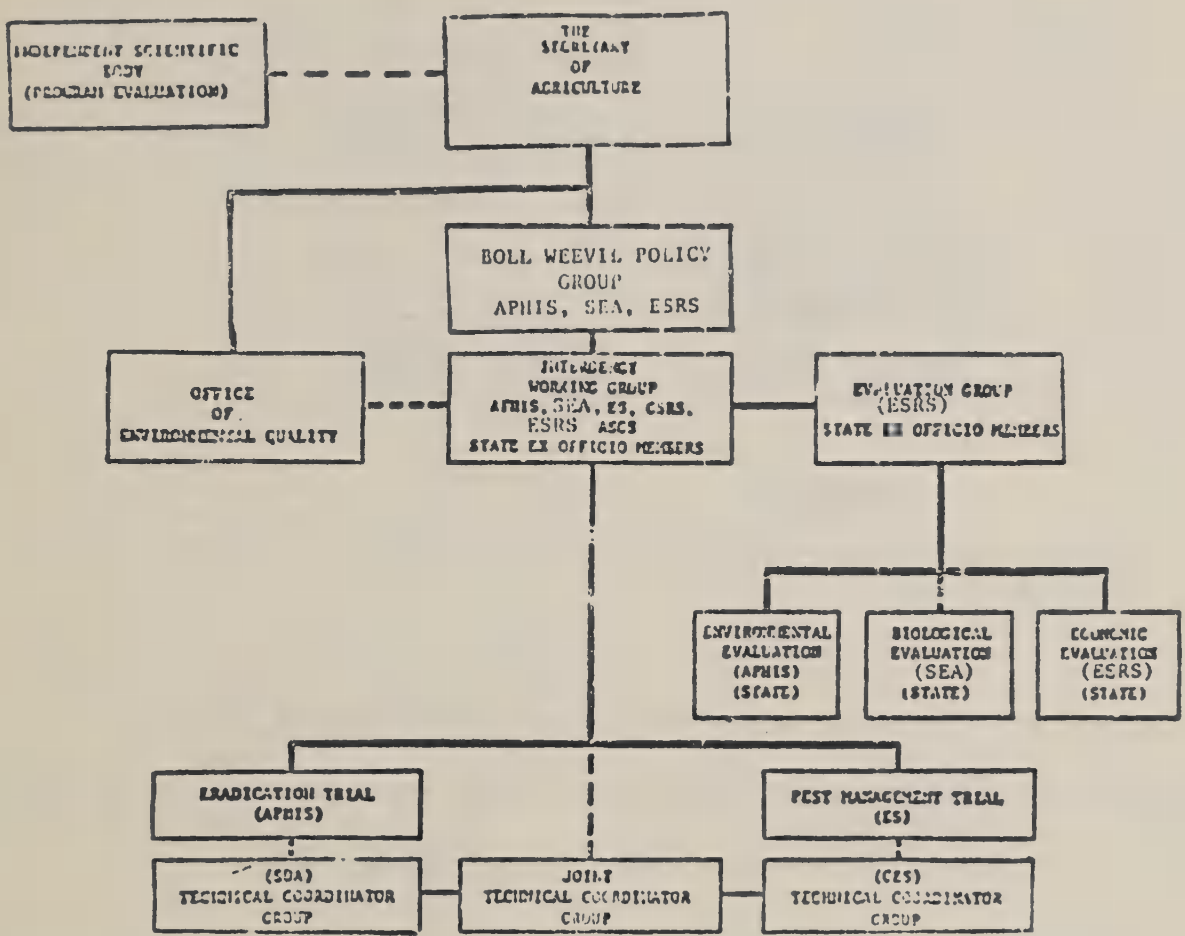

Figure 1. USDA boll weevil trials management scheme.

The role and responsibilities of each individual and group shown in the scheme are given in the Action Plans, BWET, OPM and Evaluation, May 1978, revised 1979 and 1980.

USDA - APHIS developed the boll weevil eradication operation plan and conducted the trial. Program execution at the field level was accomplished through the organization of operational personnel as shown in Figure 2.

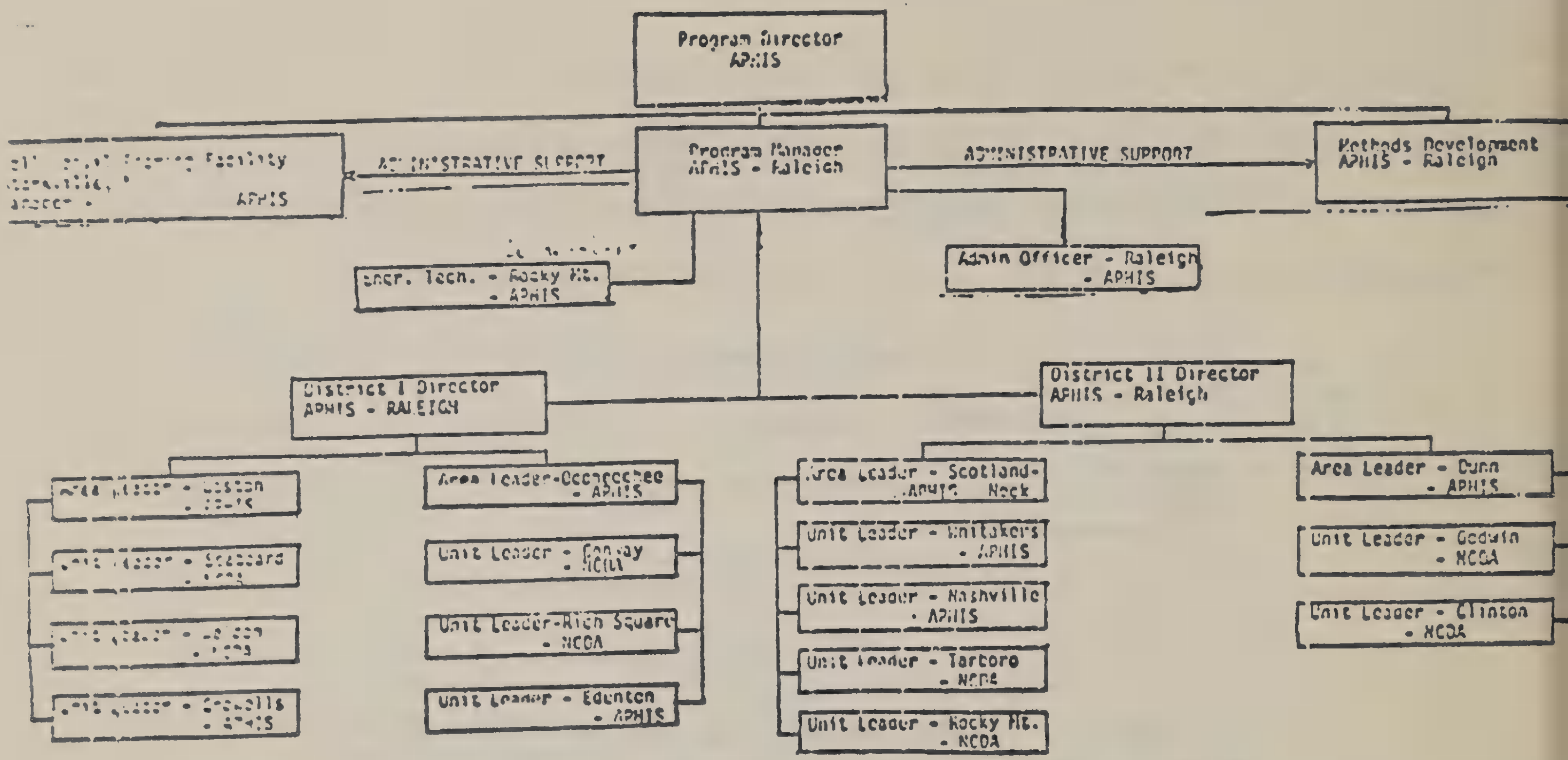

Figure 2. USDA - APHIS field level organizational chart - Boll Weevil Eradication Trial Program.

Program acreage was divided geographically into 4 work areas, each of which were subdivided into 3-5 work units. Work unit leaders were responsible for organizing and carrying out all field activities within their respective units.

The NCDA and VADAC provided regulatory and enforcement action required to carry out the trial. NCDA was custodian of the grower fund, handled most contractual services and employed temporary and some permanent personnel (Work Unit Supervisors).

Cotton producers were responsible for reporting all cotton plantings and allowing their cotton crop to be involved in all necessary program operations.

USDA - Agricultural Stabilization and Conservation Service (ASCS) registered, located and measured all cotton plantings, collected growers' share of program funds and was prepared to assist in appraisal of any cotton which should need to be destroyed because of a compliance problem.

Several other state, federal and private groups were involved in providing research, technical and advisory assistance. These functions were organized through a committee called the Technical Coordinator Group (Figure 3).

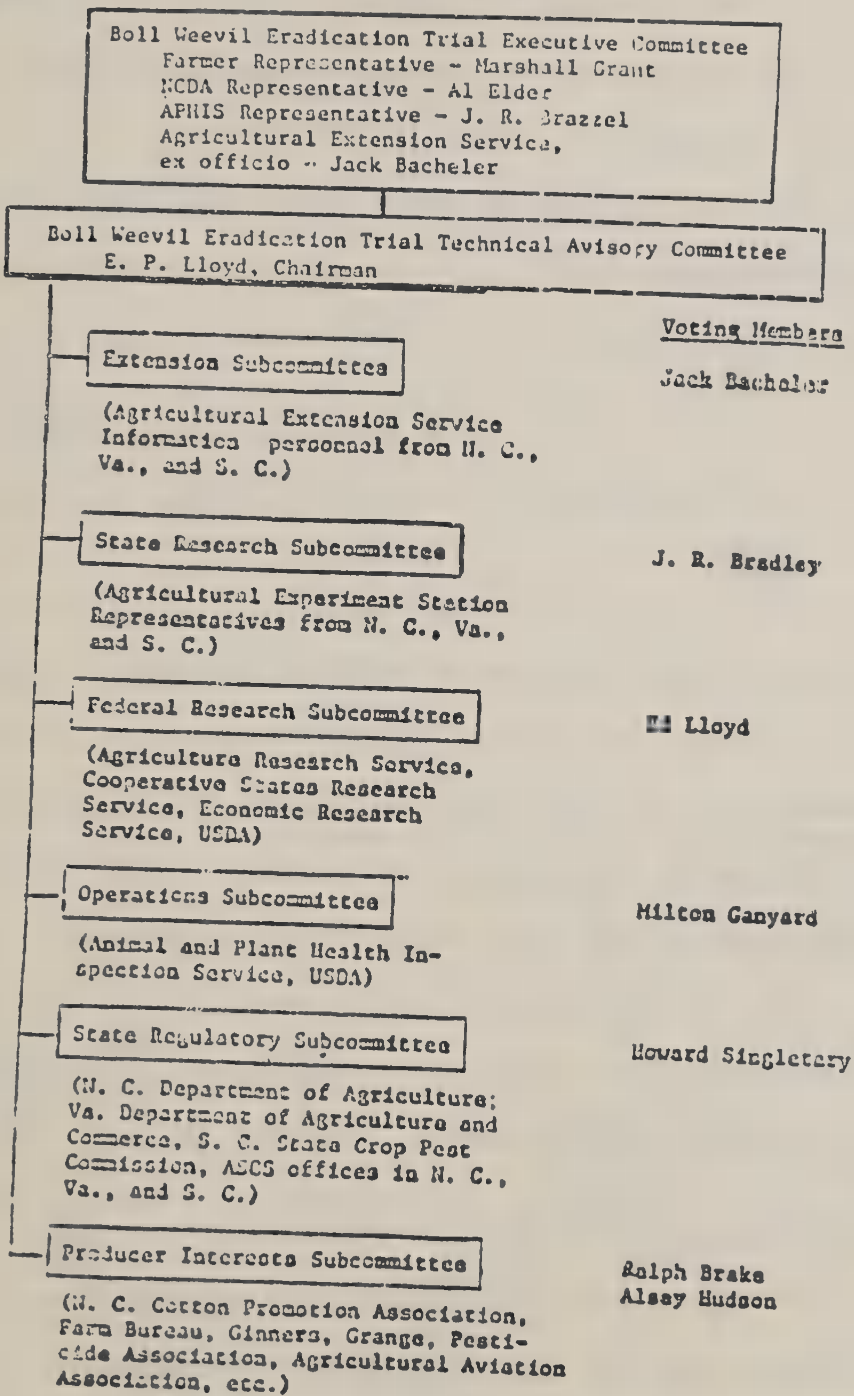

Figure 3. Technical Coordinator Group Organizational Chart - Boll Weevil Eradication Trial Program.

An extensive evaluation was conducted on the effects and results of the trial. A biological evaluation was made by a USDA-Science and Education Administration (SEA) Agricultural Research (AR) team. An economic evaluation was made under the leadership of the Economics and Statistics Service (ESS). An environmental evaluation was done under leadership of APHIS. An overall evaluation team operated under the leadership of ESS. An independent evaluation was done by a group appointed by the National Academy of Sciences.

Reporting of all aspects of the trial was coordinated through the Interagency Working Group to the Boll Weevil Policy Group which advises the Secretary of Agriculture.

The trial was designed so that eradication would be achieved through a series of suppression measures executed over the 3-year trial period. Pheromone traps were used throughout the 3-year trial period to monitor the boll weevil population. The major year 1 suppression effort was area-wide diapause control of organophosphate insecticides applied prior to and during the harvest period. In year 2, sterile boll weevils and diflubenzuron treatments were applied as needed during the early-midseason period. No suppression was required in year 3 except a diapause control treatment in the buffer zone.

Annual operating budgets were developed cooperatively by participating agencies and groups each year. This was necessary because of uncertainties in acreage to be planted to cotton each year and changing trial requirements. Operational costs per acre for the three years of the trial are given in Table 1.

Table 1. Projected and actual costs per acre for the BWET

	YEAR		
	1978	1979	1980
Projected	101.00	48.00	40.00
Actual	93.08 1/	46.95	30.58

1/ Includes cost of *Heliothis* control.

BOLL WEEVIL ERADICATION TRIAL ACTIVITIES AND RESULTS

During each year growers reported all planted acreage and paid trial fees. Trial personnel plotted fields on area photos, divided the area geographically into operational units and conducted boll weevil suppression and monitoring operations. Trail personnel also scouted for other cotton insect pests each year. In year 1 only, trial personnel also applied necessary bollworm control and defoliant materials because of the trial nature of the program. The high costs of year 1 operations was due to these additional activities which would not apply to any future boll weevil eradication program.

The trial area was divided into two zones (Fig. 4).

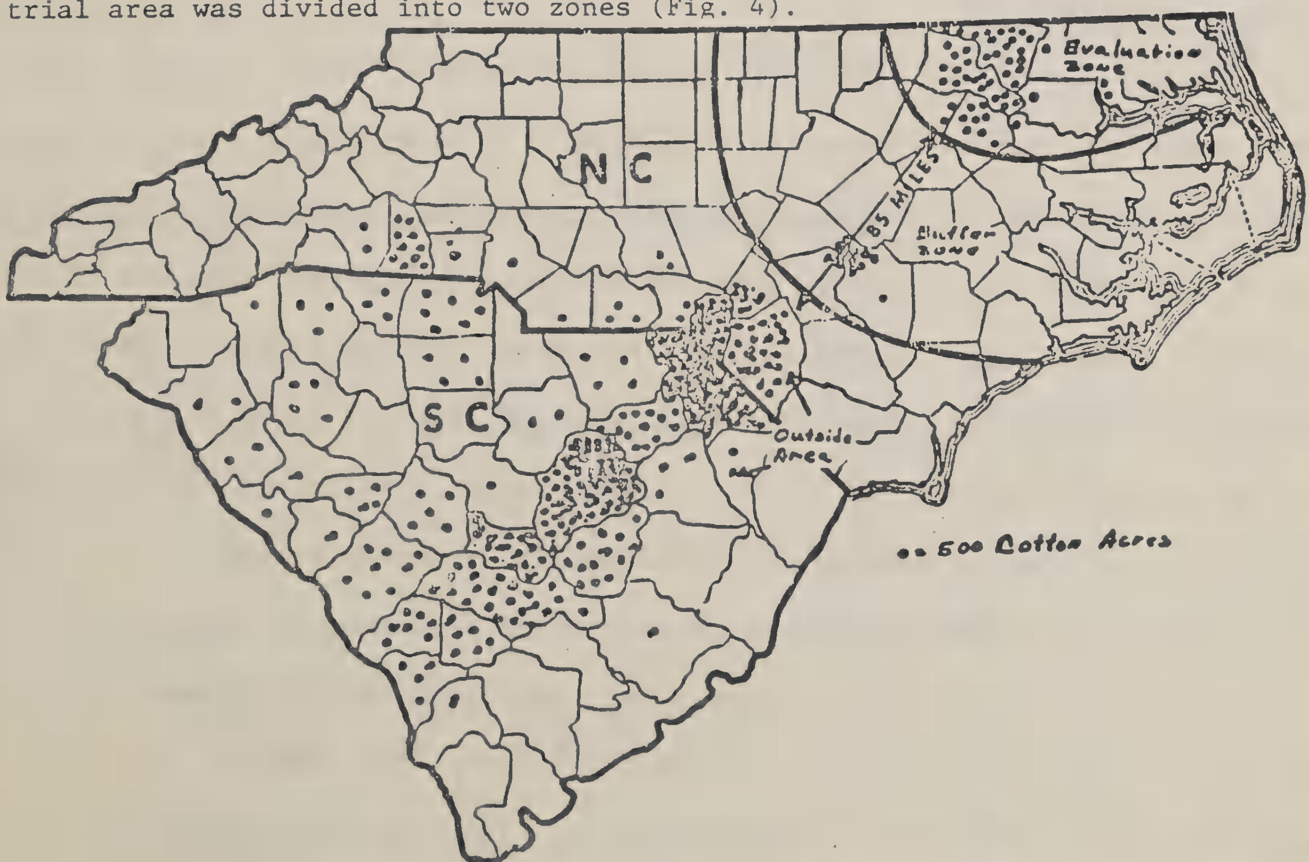

Fig. 4. Map of cotton production areas of VA, NC and SC showing locations of two zones (evaluation and buffer) relative to nearest non-program cotton acreage.

The (1) EVALUATION ZONE contained approximately 80% of the trial acreage including all cotton grown in the northeastern end of the cotton belt. This zone was the area specified for total eradication. It was separated from non-trial cotton to the south by an 85-mile wide (2) BUFFER ZONE containing the remaining 20% of the acreage. A research and development area, Chowan County, was located near the coase within the Evaluation Zone. An annual breakdown of trial area cotton production logistics is shown in Table 2.

Table 2. BWET logistics during indicated calendar years 1/

Zone	No. Cotton Acres			No. Cotton Fields			No. Cotton Growers		
	1978	1979	1980	1978	1979	1980	1978	1979	1980
Evaluation	12,485	15,222	26,729	941	1020	1775	196	201	311
Buffer	3,043	4,253	5,864	252	261	382	49	50	68
Chowan Co.1/	333	722	1,448	37	48	97	10	17	29
Total	15,861	20,208	34,041	1,230	1,329	2,229	249	268	408

1/ Beginning in 1976 Chowan County was used as an operations methods development area with some activities being tested in advance of use in remainder of trial area. area with

Suppression Activities

Table 3 shows suppression logistics for all three trial years. Year 1 (1978) boll weevil suppression activities consisted of area-wide boll weevil diapause control. Consisting of 5 organophosphate insecticide applications made during late August, September and October. Crop defoliation was combined with one of the organophosphate applications in year 1 only. Diapause treatments were applied to the majority of acreage by aircraft. Secluded areas, such as field edges which could not be treated adequately by airceaft, were treated with ground equipment such as hiboys or mist blowers mounted on four wheel drive pickup trucks.

Year 2 (1979) boll weevil suppression activities consisted of the following: (1) Aerial release of 11.2 million sterile boll weevils (139 sterile weevils per acre per week x 4 weekly releases beginning at pinhead square stage). Boll Weevils were reared and sterilized at Starkville, MS. (2) Dimilin was applied to 11%

Table 3. BWET suppression activities for indicated zones and calendar years.

		Diapause Program		Dimilin Program			Sterile Boll Weevil Program			Heliothis spp. Cont. Program		
Year	Zone	% acreage treated	Avg no. applic. per treated acre	% acreage treated	Avg no. applic. per treated acre	Avg no. applic. per program acre	% acreage treated	Avg no. applic. per treated acre	No. boll weevils released per acre per applic.	% acreage chemically treated	Avg no. Chem. applic. per treated acre	Avg. no. Chem. applic. per program acre
1978 (Year 1)	Evaluation	100	5	0	-	-	0	-	-	98	3.5	3.5
	Buffer	100	1	0	-	-	0	-	-	100	9.9	9.9
	Chowan 1/	0	-	100	6	6	0	-	-	100	5.0	5.0
1979 (Year 2)	Evaluation	0	-	6	5 2/	.30	100	4	139	89	2.5	2.2
	Buffer	100	4	11	4	.42	100	4	139	100	7.5	7.5
	Chowan	0	-	0	-	-	0	-	-	30	3.9	1.4
1980 (Year 3)	Evaluation	0	-	0	-	-	0	-	-	65	1.9	1.2
	Buffer	100	3.7	0	-	-	0	-	-	100	5.0	5.0
	Chowan	0	-	0	-	-	0	-	-	10	2.5	0.25

1/ Beginning in 1976 Chowan County was used as an operations methods development area with some activities being tested in advance of use in remainder of program area. In 1979-80 in Chowan County insect pathogens, ovicides and chemical larvicid were tested and compared for efficacy by APHIS and NC State University. Only the non-ovicide chemical applications are computed in the above data.

2/ Final application in Chowan County in 1978 and in the evaluation zone in 1979 consisted of a follow-up organophosphate application.

3/ Insecticides for Heliothis spp. control were applied by BWET personnel in 1978 and by growers at their discretion in 1979-80.

(458 acres) of the buffer zone and 6% (900 acres) of the evaluation zone acreage during June and early July. An organophosphate application was used as a closing treatment on evaluation zone acreage treated with Dimilin. (3) A diapause program consisting of 4 organophosphate treatments was applied to all cotton (4,253 acres) in the buffer zone during September and October. Sterile boll weevils were dropped on fields growing cotton in 1979. Traps to monitor boll weevil populations during this period were located around each 1978 cottonfield site. Due to rotation of cotton this resulted in sterile boll weevils being dropped at various distances from pheromone trap sites. This afforded an opportunity to measure the flight potential for sterile boll weevils. Results indicated substantial movement of these insects, evidence of their dispersal ability (figure 5).

No boll weevil suppression activities were required in the evaluation zone during year 3 (1980) because no established infestations requiring treatment were detected. A diapause control program consisting of 3.7 organophosphate applications per acre was made in September-October in only the buffer zone as result of boll weevils immigrating from outside the program area.

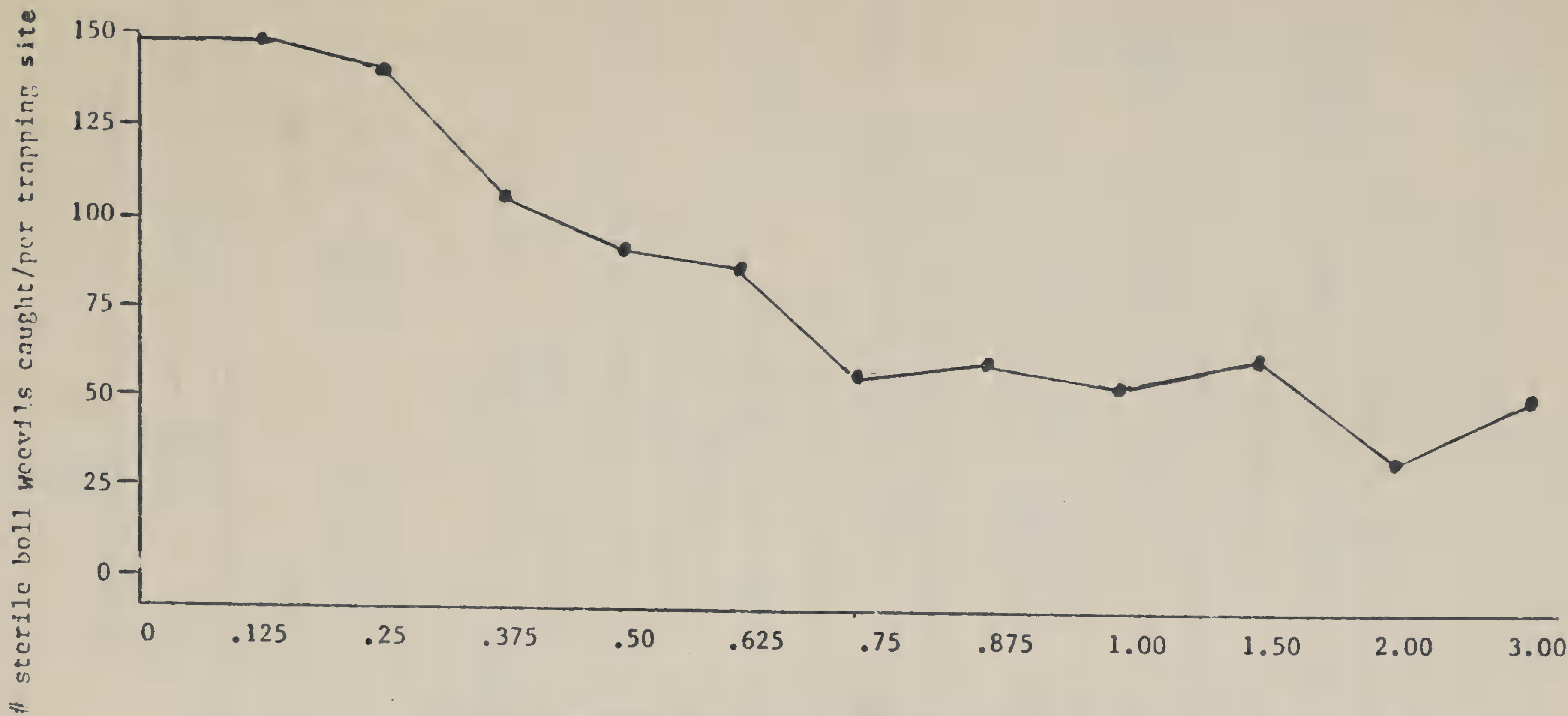

Fig. 5. Sterile boll weevil captures in traps located at varying distances from release sites

Boll Weevil Monitoring Activities

Logistics and results of boll weevil trapping activities for all 3 years are shown in Table 4.

In the fall of 1977 (year prior to program initiation) a limited trapping program was conducted in the evaluation zone. Year 1 (1978) monitoring of the boll weevil population consisted of a pheromone trapping program beginning in the spring with approximately 1 trap per 8 cotton acres (1977 acreage) located adjacent to winter hibernation sites. Trapping during the growing season and during the fall harvest period consisted of approximately 1 trap per 5 cotton acres located around the border of current cotton fields.

Year 2 (1979) trapping activities were considerably more intensive than year 1. Approximately 1 trap per cotton acre (1978 acreage) was placed near hibernation sites during the spring. During the growing season 2 traps per acre were placed infield on plants of the current crop. During the fall 1 trap per acre was operated around the edges of cotton fields.

Year 3 (1980) trapping activities consisted of locating 1 trap per 1979 cotton acre around winter hibernation sites during the spring, 1 trap per cotton acre placed infield during the growing season and 1 trap per acre operated around the edges of fields during the fall.

Trapping in the non-program cotton production area within 100 miles to the south was conducted in 1979 and 1980 (Table 3). Also, a program to study migration of boll weevils into the program area was conducted in 1979-1980 by placing traps along highways throughout the buffer zone and into the adjacent outside area. (A discussion of the migration trapping program appears in a subsequent section of this report.)

Table 4. Boll Weevil Trapping Logistics and Results for Indicated Periods and Zones (cottonfield traps only).

	No. Traps 1/			No. Boll Weevils Detected			Avg. No. Boll Weevils/1,000 Traps		
	Spring Hiber-nation Traps	Summer Infield Traps	Fall Border Traps	Spring Hiber-nation Traps	Summer Infield Traps	Fall Border Traps	Spring Hiber-nation Traps	Summer Infield Traps	Fall Border Traps
Evaluation Zone									
1977	-	-	450	-	-	1,354	-	-	3,008.89
1978	3,383	-	2,293	199	-	1,009	58.82	-	440.03
1979	14,676	30,244	19,399	7	0	2	0.48	0	0.10
1980	16,564	26,263	22,701	1	0	10 2/	0.06	0	0.44
Buffer Zone									
1977	-	-	-	-	-	-	-	-	-
1978	713	-	678	67	-	37	93.97	-	54.57
1979	3,722	4,253	3,864	38	70	867	10.21	16.46	224.38
1980	4,031	5,549	5,087	117	133	11,608	29.02	23.96	2,281.89
Chowan Co.									
1977	193	193	824	22	26	170	113.9	134.7	206.3
1978	760	-	760	10	-	0	13.2	-	0
1979	420	1,458	1,293	0	0	0	0	0	0
1980	1,117	1,548	1,548	0	0	0	0	0	0
Outside Area 3/									
1978	-	-	95	-	-	136	-	-	1,442.00
1979	712	-	1,541	3,640	-	117,894	5,112.36	-	76,504.87
1980	1,559	-	1,512	78,478	-	483,260	50,338.68	-	319,616.40

1/ Spring hibernation summer infield and fall border traps were generally operated April 15–July 30, July 15 August 30, and September 1–November 1, respectively.

2/ All 10 boll weevils detected were in one localized portion of a single cotton field. An additional 4 boll weevils were captured in migration traps located away from cotton fields in the southern edge of the evaluation zone. Total detections in the evaluation zone in 1980 = 15 boll weevils.

3/ Outside area constitutes a survey of sample cotton fields within a 100 mile area south from the outer buffer zone boundary. South Carolina trapping coordinated by Clemson University, Clemson, SC.

In the 1977 fall trapping program conducted in the evaluation zone, a total of 1,354 boll weevils was captured in 450 traps (average of 3,009 per 1,000 traps) for the 6-week period. These results indicated the native boll weevil population was low compared with average historical levels. The year, 1977, was preceded by an abnormally cold winter which suppressed the boll weevil population throughout the southeastern states. Also, 1976 and 1977 were characterized by above normal Heliothis spp. problems. The attendant intensive use of organophosphate materials on a high percentage of acreage provided further abnormal suppression on boll weevil.

Spring 1978 trapping results confirmed the existence of a low level boll weevil population. Consequently, with the exception of a few more heavily infested acres near Scotland Neck, Halifax County, no suppression activities were conducted in 1978 for boll weevil until the diapause control program was initiated in early September. Incidental boll weevil suppression earlier in the season was obtained from an average of 3.5 chemical insecticide applications made for Heliothis spp. during the latter half of August and early September in the evaluation zone and 9.9 applications made during late July, all of August and early September in the buffer zone.

The year 1 trial goal was to reduce the boll weevil population to a level no greater than 3 adults per cotton acre. Late season captures during 1978 (August-November) of 1,046 boll weevils in 3,731 traps in the evaluation zone were used to extrapolate that no more than an average of 0.3 boll weevil per cotton acre entered hibernation quarters (a 10X lower level than established as the goal for year 1).

In early 1979, a total of 7 widely spearated boll weevils were captured in 14,676 evaluation zone traps located near hibernation sites from mid-April to the end of July (14 weeks). No boll weevils were caught in an additional 30,244 evaluation zone traps located within cotton fields during July and August (8 weeks). Only 2 widely separated boll weevils were captured in 19,399 border traps during the fall

diapausing period. Thus 9 boll weevils were caught and no reproducing boll weevil populations were detected in the evaluation zone during the 1979 cotton production season.

In 1980 one boll weevil was captured prior to August 18 in 16,564 - 26,263 traps in the evaluation zone. This boll weevil was removed from a trap about 5 miles northwest of Scotland Neck, Halifax County, on May 6 and is considered a false capture. The boll weevil body was partially disintegrated and the head was missing. The trap had been recycled from the previous season's trapping program. The trap was probably used in the outside trapping program during the fall of 1979 and was not properly cleaned prior to usage in 1980.

In the evaluation zone 4 boll weevils were captured in migration survey traps during 1980. Two of these were captured near Spring Hope, Nash County, NC on August 18 and September 15. A third boll weevil was removed from a trap 2 miles north of Wilson, Wilson County on August 18. The fourth boll weevil was removed from a trap near Louisburg, Franklin County on October 28. All of these locations are in the southwestern fringe of the evaluation zone and none of them are near cotton fields (Figure 7).

On September 11, 1980 a boll weevil was captured at a 10 acre cotton field 1/2 mile south of the VA state line; 2.5 miles northwest of Gaston, Northampton NC. This location is about 90 miles north of the nearest known infested cotton field in the buffer zone. The cotton crop in this and all surrounding fields had been under severe drought stress all summer. Only a few spots along margins of the reinfested field contained unopened bolls which could yield a developing or entrapped boll weevil. All mature fruiting forms which could be found (an estimated 3,500) were examined. Trapping in the 10 acre field was intensified from 10 to 116 traps. Trapping was increased from 1 to 2 traps per acre in all cotton fields within a 1-1/2 mile radius of the localized reinfestation. Between September 15-24, an additional 9 boll weevils were detected

at the same site, of which 6 were found through trapping. Three of the 9 boll weevils were found inside unopened bolls on September 16. One was a pupa and two were entrapped adults. The field containing the localized reinfestation was harvested and the stalks destroyed during the period between September 15-24. Other than the intensified trapping mentioned above, no other suppression measures were used and no boll weevils were captured at any other fields. Trapping was continued until November 15 (7 weeks) and no additional boll weevils were captured at the infested location. This was the only detection of boll weevils at a cotton field in the evaluation zone in 1980 except the headless boll weevil from a recycled trap near Scotland Neck detected on May 6. At the time this report was prepared (February 1981), this was the only case of boll weevil reproduction known to occur in the evaluation zone after October 1978 (29 months).

Based on the known capture efficiency of the trapping system and the dynamic reproductive ability of the boll weevil, it is concluded that the native boll weevil population was eliminated in the evaluation zone during July 1979. The 2 fall 1979 catches would, therefore, represent reintroduced boll weevils. The first of these 2 boll weevils was removed from a trap on October 11, 1979 at a cotton field near a motel complex on Highway I-95 north of Rocky Mount Nash County, NC. It is conceivable that this boll weevil arrived in this area via a tourist who removed part or all of a cotton plant from an infested field south of the trial area and accidentally transported the boll weevil to an overnight stop. The second fall 1979 boll weevil capture was removed from a trap at a field about 1 mile from an APHIS field office on November 6. Employees from this location had been assisting in trapping activities in the buffer zone a few weeks prior to the catch and may have accidentally transported this boll weevil back into the area. As will be discussed later, migration trapping results in 1980 could also support the conclusion that both fall 1979 boll weevil captures were within the range of migrating boll weevils from infested cotton to the south. No reproductive populations resulted from these two cases of reintroduced boll weevils in 1979.

We believe that the highly localized reinfestation which occurred near Gaston, NC between September 11 and September 24, 1980 was due to the arrival in the area of a single previously mated female in August. The 10 boll weevils detected at this location during September 11-24 would likely represent the F_1 offspring of this female. This detection by pheromone traps supports research data that the trapping system as employed in the trial is capable of detecting a reinfestation in the F_1 generation.(Lloyd, et al 1980, Leggett, et al 1980).

BOLL WEEVIL MIGRATION TOWARD THE EVALUATION ZONE

In 1978 the USDA - SEA Boll Weevil Eradication Research Group installed pheromone traps along two highway lines leading from outside non- trial cotton acreage into the evaluation zone. In the fall of 1979 APHIS added several more lines of traps throughout the buffer zone. The purpose of this trapline network was to define boll weevil immigration from nearby infested cotton acreage.

Results of trapping on the two SEA lines from 1978-80 are reported elsewhere (Lloyd et al 1980). Results of trapping on both the APHIS and SEA network in 1979 are shown in figure 6.

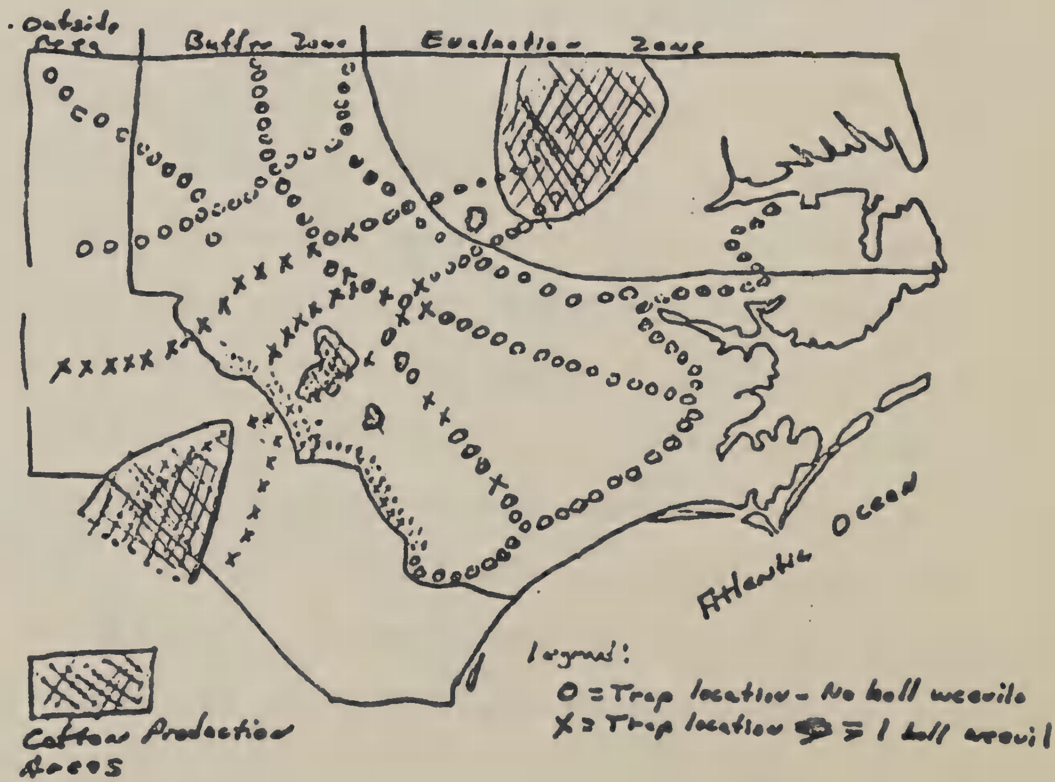

Figure 6. Locations of USDA - APHIS and USDA - SEA traplines and migrating boll weevil captures - 1979.

In 1980 pheromone traps were placed on a 3-mile grid pattern throughout a 45-county area covering the buffer zone and extending both into the nearby non-trial area and into the southern edge of the evaluation zone (Figure 7).

1980 migration trapping results show a continuous but decreasing gradient of boll weevil captures across the buffer zone from the outside infested cotton production area in Scotland, Hoke and Robeson counties, NC, north and northeast to a curved line running roughly from Asheboro through Raleigh to Goldsboro (Figure 8). This is a distance of about 65 miles from the northernmost fields of the infested cotton production area to the south. A few scattered boll weevil captures occurred up to 25 miles north of this line, for a total of 90 miles from the outside infested area. Boll weevil captures in the migration traps were most numerous in August and September, with the August total being the greater (Figure 9).

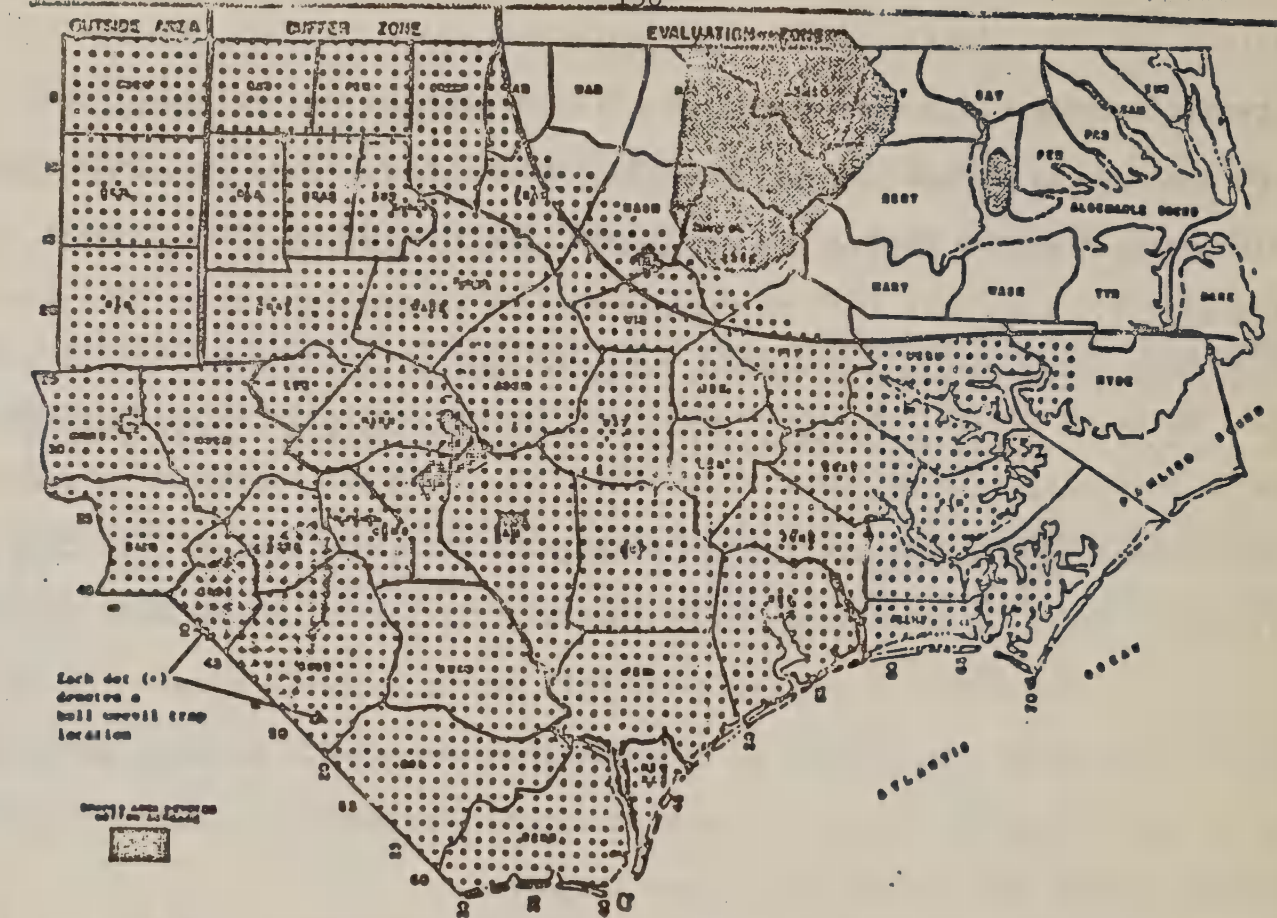

Figure 7. Locations of traps installed on a 3-mile grid pattern to detect migrating boll weevils, 1980.

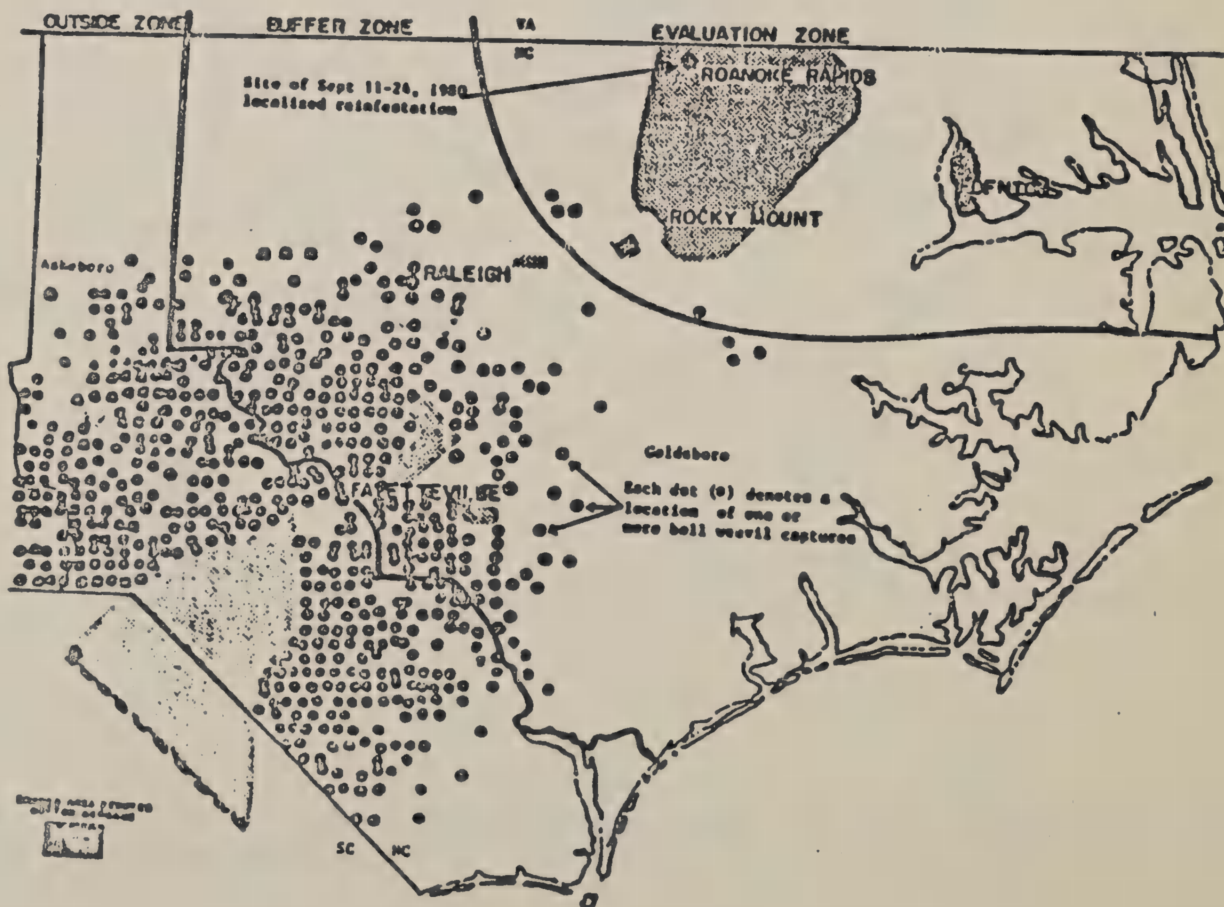

Figure 8. Locations which captured migrating boll weevils in 1980.

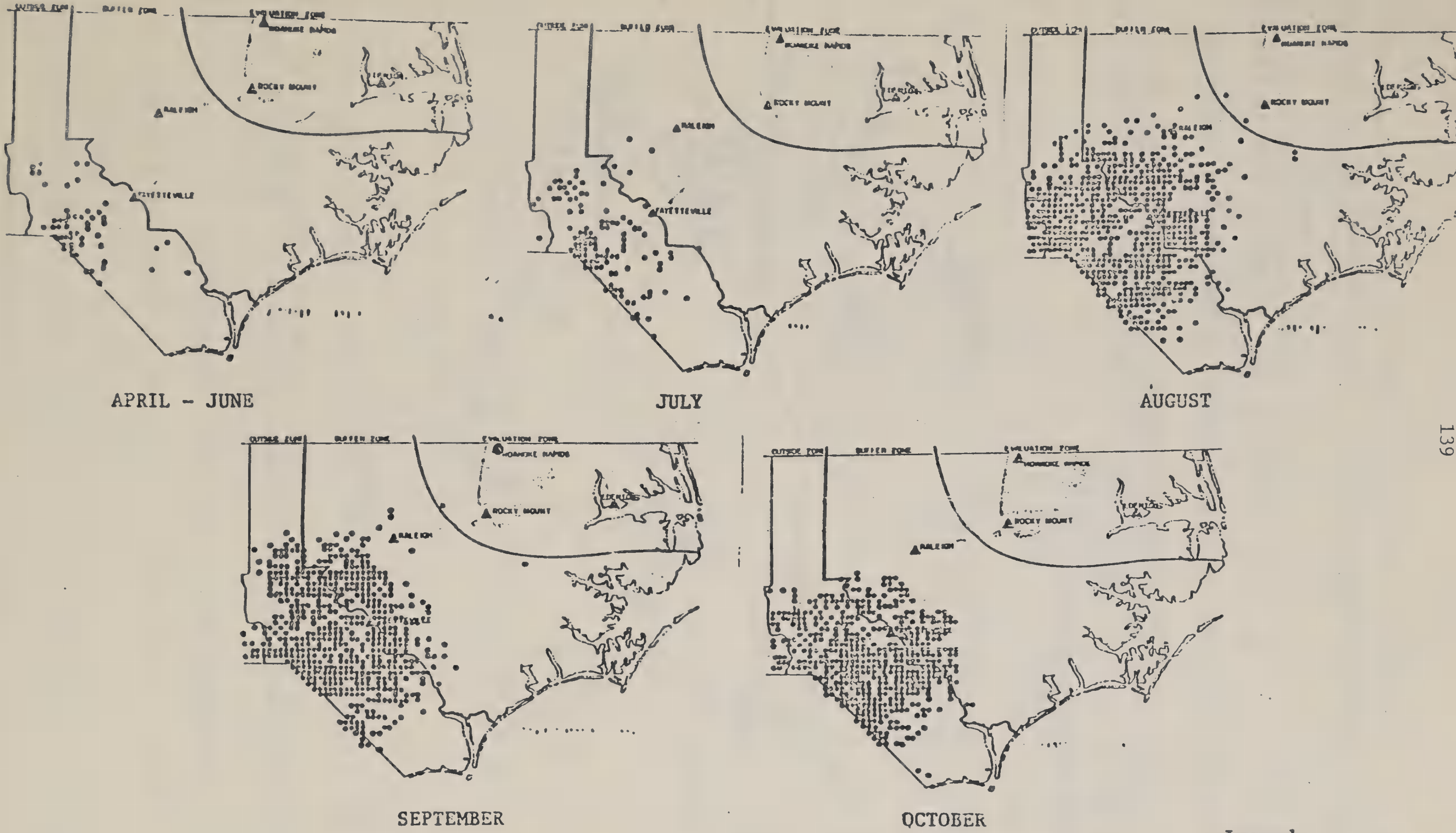

Figure 9. Periodic breakdown of migrating boll weevils captured during 1980.

Legend:

● = Location capture[d]
1 or more boll
weevils

Figure 10 shows the northernmost detections of migrating boll weevils each year, 1978 (after Lloyd et al), 1979 and 1980. Migratory boll weevils were captured further north in 1980 than during the two previous years. It is difficult to conclude whether these results are due to more northern movement in 1980, to the intensified trapping, or both. As shown in an earlier section of this report there was a substantially higher boll weevil population in adjacent non-trial cotton acreage in 1980 than during the two previous years.

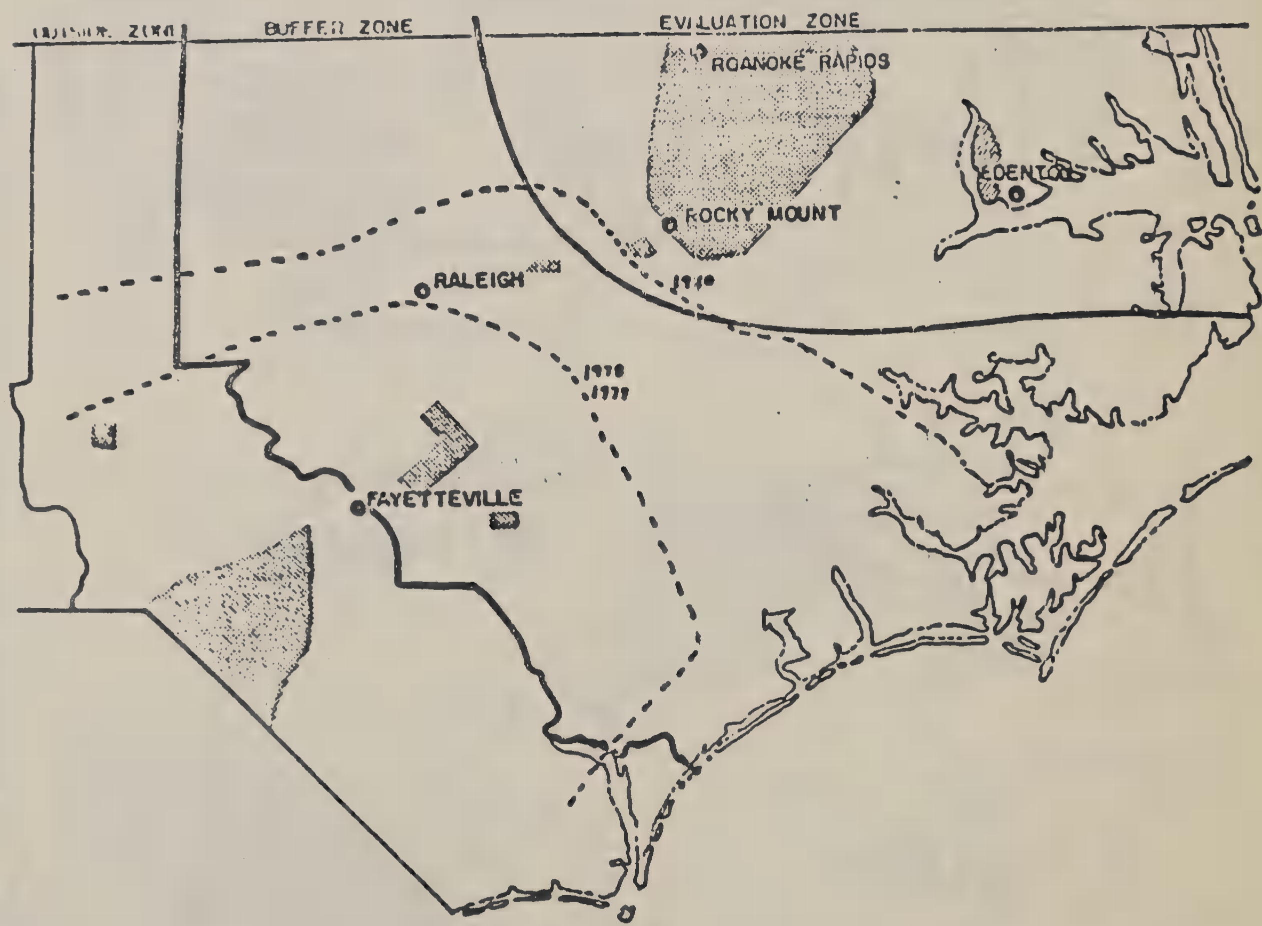

Figure 10. Northernmost detection of migrating boll weevils 1978, '79, '80.

Figure 11 shows numerical comparisons of boll weevil migration captures and percent females at varying distances into the eradication trial area. No differences could be seen in sex ratio of boll weevils captured as the distance increased from the infested cotton acreage into the trial area.

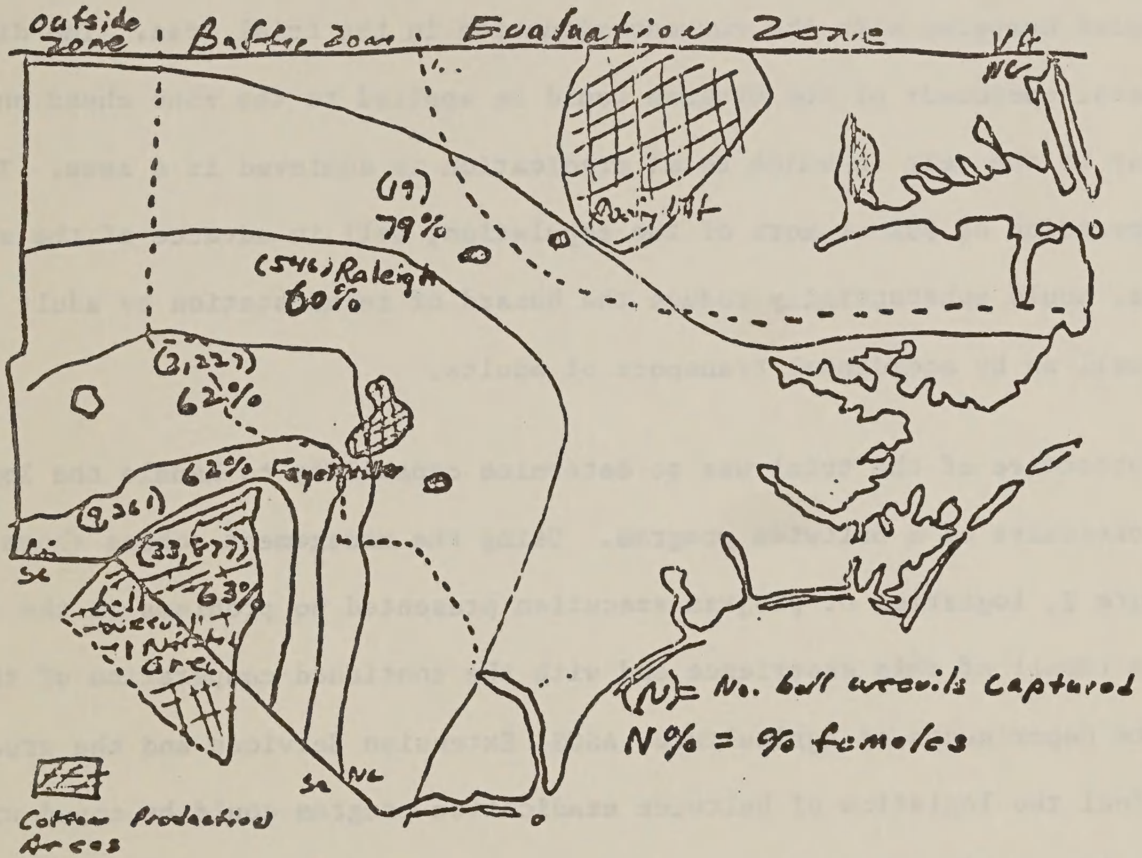

Figure 11. Migration trapping results showing total boll weevils captured and percent females at varying distances from boll weevil infested area south of trial area.

Based on results of migration studies for 3 years it presently appears that an 85-mile wide buffer zone is sufficient to prevent the liklihood of a permanent reinfestation. This assumes that the buffer zone is either free of cotton acreage or the boll weevil is kept at low population levels where cotton acreage exists within the zone. Obviously some boll weevils will occasionally become reintroduced in a static situation where infested acreage is within 85 miles. When a fertile female penetrates the eradicated zone and locates fruiting cotton plants some liklihood exists of offspring being produced. However, it is expected that where reinvasion consists of scattered, single re-entries, many naturally occurring factors would serve to minimize the chances of a permanent reinfestation becoming established.

BELTWIDE IMPLEMENTATION

In a beltwide eradication program the hazard of reinvasion would be greatly reduced compared with the current situation in the trial area. The diapause control component of the program would be applied to the zone ahead one year prior to the year in which total eradication is achieved in a zone. The suppression of 99% or more of the population, well in advance of the eradicated area, would substantially reduce the hazard of reinfestation by adult dispersal as well as by accidental transport of adults.

An objective of the trial was to determine capability to handle the logistics in executive of a beltwide program. Using the management scheme shown in Figure 2, logistics of program execution presented no problems in the trial. As a result of this experience and with the continued cooperation of the State Departments of Agriculture, ASCS, Extension Services and the growers, we feel the logistics of beltwide eradication program could be coped with, even though greater acreage of cotton than in the trial would be involved.

Another important condition which bears on operational feasibility is the availability of manpower locally to execute the program. No problems encountered in employment of adequate personnel during the conduct of the trial and we assume this would be the case across the beltwide area. Based upon experiences in the trial, a beltwide eradication program is considered operationally feasible.

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